

SCHLIEREN OBSERVATION OF
SUPERSONIC DISCHARGE

E. L. PERRY,
L. W. A. RENSHAW

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Department of Mechanical Engineering
Cambridge 39, Mass., U.S.A.

Room 1-202

September 24, 1946

Captain W. H. Buracker
Room 5-233
Massachusetts Institute of Technology
Cambridge 39, Massachusetts

Thesis Work of LT E. L. PERRY, USCG ←
LT L. W. A. RENSHAW, USCG
LCDR W. W. SIMONS, USN
LCDR J. S. BOWEN, USN

Dear Captain Buracker:

The thesis by Lieutenants E. L. Perry and L. W. A. Renshaw entitled "Schlieren Observation of Supersonic Discharge" presents pressure measurements and Schlieren photographs of supersonic streams discharging into an exhaust space under various conditions. The photographs show interesting detail which in general corresponds to analytical results. The most significant observation was a comparison of two supersonic streams alike in average conditions but differing in thickness of the boundary layer. The effect of boundary-layer thickness on the nature of the shock pattern is shown clearly.

The thesis by Lt. Comdrs' W. W. Simons and J. S. Bowen entitled "Investigation of the Condensation Shock in Air by Use of the Schlieren Method" presents pressure measurements and Schlieren photographs of the shock patterns when water vapor in air condenses to form a fog of liquid or solid particles. It has extended our knowledge of the conditions which control condensation and of the condensation shock which accompanies it.

From either of these theses a paper could be prepared which would be published in one of the journals of the professional societies.

Yours truly,

/s/ Joseph H. Keenan

Joseph H. Keenan

497
SCHLITZEN ORIENTATION

OF

SUPERSONIC DISCHARGE

BY

Lieut. E. L. Perry
B.S., U.S.C.G. Academy
1941

and

Lieut L.W.A. Penahan
B.S., U.S.C.G. Academy
1941

Submitted in partial fulfillment of the
requirements for the degree of
Master of Science

at the

Massachusetts Institute of Technology

1946

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY
77 Massachusetts Avenue
Cambridge, Massachusetts

September 15, 1946

Professor Joseph S. Newell
Secretary of the Faculty
Massachusetts Institute of Technology
77 Massachusetts Avenue
Cambridge, Massachusetts

Dear Professor Newell:

Herewith we submit our thesis entitled "Schlieren
Observation of Supersonic Discharge" in partial fulfillment of the
requirements for the Degree of Master of Science in Naval
Construction and Engineering at the Massachusetts Institute of
Technology.

RESEARCH IN PHYSICS
IN THE
UNIVERSITY OF CHICAGO

September 15, 1946

Dear Mr. [Name]

Enclosed for you are
three copies of the
report of the
committee on the
status of the
department.

Very truly yours,

Robert A. Serber, Chairman

Enclosed for you are also three copies of the

report of the committee on the status of the

department and the report of the committee on the

status of the

Very truly yours,

[Signature]

[Signature]
[Name]

ACKNOWLEDGEMENT

With pleasure we acknowledge the help given us by Professor Joseph H. Keenan and Professor E. P. Neumann of the Mechanical Engineering Department. Thanks are also due to Dr. Joseph Kaye and Mr. Ferdinand Lustwerk. Mr. Lustwerk rendered invaluable assistance in developing laboratory equipment and technique.

Professor Joseph H. Keenan suggested the thesis topic.

Introduction

The purpose of this study is to investigate the effects of various factors on the growth and development of the human body. The study is designed to provide a comprehensive overview of the physical and physiological changes that occur during the process of growth. The research is based on a review of the existing literature and the results of a series of experiments conducted over a period of six months. The findings of the study are presented in the following sections.

The first section of the study is a review of the literature on the topic of growth and development. This section provides a historical perspective on the study of growth and development and identifies the key areas of research that have been explored in the field. The second section of the study is a description of the methods used in the research. This section details the experimental design, the subjects of the study, and the procedures used to collect and analyze the data.

The third section of the study is a presentation of the results of the research. This section includes a detailed description of the physical and physiological changes that were observed in the subjects of the study. The results are presented in a series of tables and graphs, which illustrate the relationship between the various factors and the growth and development of the human body.

The fourth section of the study is a discussion of the implications of the findings. This section explores the potential applications of the research and discusses the limitations of the study. The final section of the study is a conclusion, which summarizes the main findings of the research and provides a final statement on the importance of the study.

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LXXXXV	95
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LXXXXVII	97
LXXXXVIII	98
LXXXXIX	99
LXXXXX	100

SUMMARY

This work was undertaken to observe the effect on the discharge phenomenon of a supersonic air stream due to a change in Mach Number and a change of boundary layer thickness at constant Mach Number. Two (2) two-dimensional nozzles were designed using the Prandtl Theory, one having a Mach Number of 1.85 and the other a Mach Number of 1.39. A third nozzle was formed by adding a length of straight tube to the profile of the first nozzle to bring the Mach Number down to 1.39 by friction. All nozzles were designed for the same flow per unit area in the exit.

A comparison of the discharge of the first and second nozzles should show the effect of Mach Number, whereas a comparison of the second and third nozzles should show the effect of boundary layer thickness. The comparisons were made by Schlieren photographs and pressure measurements by mercury manometers at a point one eighth ($1/8$) inch from the exit of the nozzle and in the discharge chamber. It is noted that the nozzles were mounted perpendicular to the knife edge in the apparatus.

The results of the first comparison are not too conclusive. Further study in this line is recommended. The second comparison shows that a thick boundary layer cannot support anything resembling a transverse shock whereas a thin boundary layer will. Pressure measurement revealed that even in the thinnest boundary layers we were able to obtain there was no abrupt rise in pressure in the exit of the nozzles - like that expected in frictionless flow - as the exhaust pressure was increased. It is pointed out that the pressure was measured at the wall at a point one eighth ($1/8$) inch from exit. The photographs show that as the exhaust pressure is increased, the

This was not intended to measure the effect of the
placement of a specimen in a position of a change in the
and a change in density from thickness at constant time
The [2] experimental results were designed using the French theory
was having a thick layer of 1.50 and the other a thin layer of 1.25
A first result was found by using a layer of thickness 1.50 in the
results of the first series in using the thin layer was 1.25 by
relation. All results were designed for the same time but were
in the exit.

A comparison of the thickness of the first and second series
should show the effect of both factors, change a comparison of the
results and which series should show the effect of density and
thickness. The comparison was made by following procedure and
pressure measurements by means of a gauge was about 1.50
from the wall of the vessel and in the thickness of the wall
which the results were plotted graphically in the table
in the apparatus.

The results of the first experiment are not too conclusive.
Further study in this line is recommended. The second experiment
shows that a thick boundary layer means a great weight resulting
a pressure which shows a thin boundary layer will. Pressure
measurements revealed that even in the thinnest boundary layers no
more will be found there are no sharp rise in pressure in the wall
of the vessel. This was expected in relation to the results of the
second pressure was measured. It is pointed out that the pressure
was measured at the wall of a point was about 1.50 from the wall.
The investigation shows that as the initial pressure is increased, the

oblique shock tends to creep back from the exit. This is shown in Figures VIII, IX and X. The gradual rise in exit pressure shown by our measurements may be due to this creeping back of the oblique shock over the pressure tap. Figure I shows that there were slight discontinuities in the pressure curve for the high Mach Number discharge. The photographs in this region - Figures XI, XII and XIII - depict this instability in the flow.

It is recommended that further work of this nature be carried out with the nozzles mounted parallel to the knife edge of the Schlieren apparatus in order to observe more precisely the contribution of the boundary layer to the discharge phenomena.

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INTRODUCTION

The academic interest in the flow of fluids at supersonic velocities has recently become of practical importance due to the development of gas turbines etc. The theory of the manner in which a supersonic stream from a nozzle or tube adjusts itself to the pressure in the exhaust space is well developed.

This work proposes to investigate and observe by Schlieren methods of photography the manner in which such adjustments are accomplished and the effects of different Mach Numbers and different boundary layer thicknesses on the phenomena.

The student's interest in the flow of fluids is emphasized
by the study of the principles of hydrostatics and the
application of the principles of fluid mechanics to the
study of the flow of fluids in pipes and channels.
The pressure in the exhaust space is well developed.
The study of the principles of hydrostatics and the
application of the principles of fluid mechanics to the
study of the flow of fluids in pipes and channels.
The pressure in the exhaust space is well developed.
The study of the principles of hydrostatics and the
application of the principles of fluid mechanics to the
study of the flow of fluids in pipes and channels.

PROCEDURE

Three (3) two-dimensional nozzles were designed. These were fitted with plane glass sides so that the flow in the exit and discharge chamber could be observed by a Schlieren apparatus. The first of these nozzles (designated Nozzle #1 and shown in Figure XXXVI, Appendix B) was designed to have as little boundary layer as possible and a Mach Number of 1.85. The second nozzle (designated Nozzle #2 and shown in Figure XXXVII, Appendix B) was designed for the same flow per unit area at the exit and a Mach Number of 1.39. A comparison of these two nozzles should show some effect of Mach Number change on the discharge. The boundary layer should be small in each since they are very short.

To compare the discharge at the same Mach Number and different boundary layer thicknesses a straight portion was added to the contour of Nozzle #1 to reduce the Mach Number by friction to the same value as that of Nozzle #2 - (1.39). It was anticipated that some adjustment of the length of the straight portion would have to be made to bring the Mach Number to 1.39. This was later found to be the case.

The laboratory procedure consisted of mounting the nozzles in the Schlieren apparatus and taking suction with a steam jet air ejector. Air at room temperature and atmospheric pressure was used as supply to all the nozzles. It is noted that in order to maintain the same flow per unit area for Nozzle #2, a specially designed reducing fitting shown in Figure XXXIX was used to reduce the inlet pressure to two thirds ($2/3$) atmosphere.

Starting with the lowest pressure we could obtain in the

discharge the exhaust pressure was allowed to increase in steps until the pressure shocks were seen to move back into the nozzle. Readings of the exhaust pressure and the pressure one eighth ($1/8$) inch upstream from the exit plane were made by mercury manometer and recorded. Photographs were made at each step using the Edgerton Flash Unit described in Reference (1). Graphs of exit pressure vs exhaust pressure were plotted,

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RESULTS AND DISCUSSION OF RESULTS

The results of the experiment are shown in Figures I to XXXV.

A comparison of Figure I and Figure II would indicate that a phenomenon more closely approaching a theoretical transverse shock is found in flow at higher Mach Number. The break in the pressure curve for Nozzle #1 (Mach Number 1.85) at an exhaust pressure of about 240 mm Hg. is much more pronounced than for any in the curve for Nozzle #2 (Mach Number 1.39). Examination of Figures X, XI and XII shows some instability of the discharge at the instant the shock occurs at the exit of the nozzle for the higher Mach Number. No such instability was observed at the lower Mach Number (1.39). Figures XXV, XXVI and XXVII show, however, what appears to be a transverse shock at the lower Mach Number. It is believed that the comparatively smooth pressure curve for Nozzle #2 is caused by the length of the shock. Apparently the flow separates from the tube wall near the exit and the shock passes smoothly up the nozzle as the exhaust pressure increases ; whereas at the higher Mach Number the shock is much shorter and the flow less stable. We were unable to stop the shock in the exit of this nozzle.

Under all conditions the pressure in the stream adjusted itself to a lower exhaust pressure by the expansion wedges expected from the Meyer Theory of flow around a corner. This is shown in Figures IV, XXII and XXVIII. Small and moderate adjustments to a higher exhaust pressure were made in all cases by the medium of an oblique shock. There was a tendency for the oblique shock to creep back into the nozzle as the exhaust pressure increased. It is observed that this tendency became very pronounced in the case

of the thick boundary layer. It is possible that the gradual rise in the observed exit pressure as the exhaust pressure is increased is due to the oblique shock creeping back over the pressure tap which is located one eighth ($1/8$) inch from the exit. In that event the observed pressures are probably not the true pressures in the center of the stream at exit.

A comparison of Figure II and III show a marked similarity in the pressure relations of the two discharges at the same Mach Number (1.39) but different boundary layer thicknesses. It is noted that the curve for Nozzle #3 with a thick boundary layer is displaced to the right by about 15 mm Hg. on the exhaust pressure scale.

The mechanism by which the pressure in the stream adjusts itself to a considerably higher exhaust pressure is shown in Figures XXXII to XXXV and Figures XXIV to XXVII to be somewhat different in these two cases. In the case of the thick boundary layer Figures XXXII to XXXV show that nothing resembling a transverse shock occurs. Instead, the boundary layer, which is subsonic, appears to increase in area while the supersonic stream decreases in area; thus the pressure rises to that of the exhaust chamber. The oblique shocks which are set up and reflect downstream appear to originate at the point where contraction of the supersonic stream begins. It is possible that this apparent enlargement of the boundary layer cross section is actually a flow separation from the wall. The observation that this phenomenon occurs only in the case with thick boundary layer supports the former assumption, however.

It is recommended that further work on this point be carried

of the thick boundary layer. It is possible that the physical time

It is the purpose of this report to present a summary of the results of the study of the effect of the concentration of the solution on the rate of the reaction.

[illegible]

It is recommended that further work on this topic be carried

out with the nozzle mounted parallel to the knife edge of the Schlieren apparatus so that a better idea of what is going on in the boundary layer may be obtained.

In the case of the thin boundary layer no such separation or enlargement is observed. What appears to be a transverse shock with perhaps a little separation is shown in Figures XXiv to XXVII.

Investigation of the effect of Mach Number on the discharge with thick boundary layer is also recommended. It would be interesting to make observations at a Mach Number of 1.39 and with a boundary layer intermediate in thickness between the two cases used in this work.

As is noted in Appendix A the length of straight tube necessary to reduce the Mach Number of Nozzle 1 to that of Nozzle 2 was calculated to be 10.35 inches. Actual experiment revealed that this value should be 6.02 inches and the length was accordingly reduced to that value.

Due to extremely low temperatures of the stream it was practically impossible to prevent the condensation of moisture on the outside surfaces of the glass plates. This resulted in smudges similar to those shown in Figures IX, X, XXVIII and XXX.

and with the sample treated parallel to the knife edge in the
direction of the sample in such a fashion that it is found to be
the boundary layer may be obtained.

In the case of the thin boundary layer in some instances the
alignment is observed. The sample is to be a boundary layer with
perhaps a little separation is shown in Figure III in III.
Investigation of the effect of such factors on the boundary layer
often boundary layer is also considered. It would be interesting to
also investigate on a thin layer of 1.15 and with a boundary layer
relationship in thickness between the two cases and in this way.
As it is found to be similar to the layer of thickness in this case
to reduce the case factor of Figure I in that of Figure 2 and indicated
to be 1.15 factor. In such a case it is found that this value should
be 1.15 factor and the layer is approximately reduced to that value.
The is not only the comparison of the value of the
thickness in this case to the thickness of the layer in the
other cases in the same layer. This is called in Figure
which is shown above in Figure I, I, Figure III and III.



FIGURE I

NOZZLE 1

P_e = Exhaust Pressure

P_g = Pressure in Exit

Nozzle Inlet Pressure 761.2 mm Hg.

Inlet Temp. 85° F.

July 19, 1946

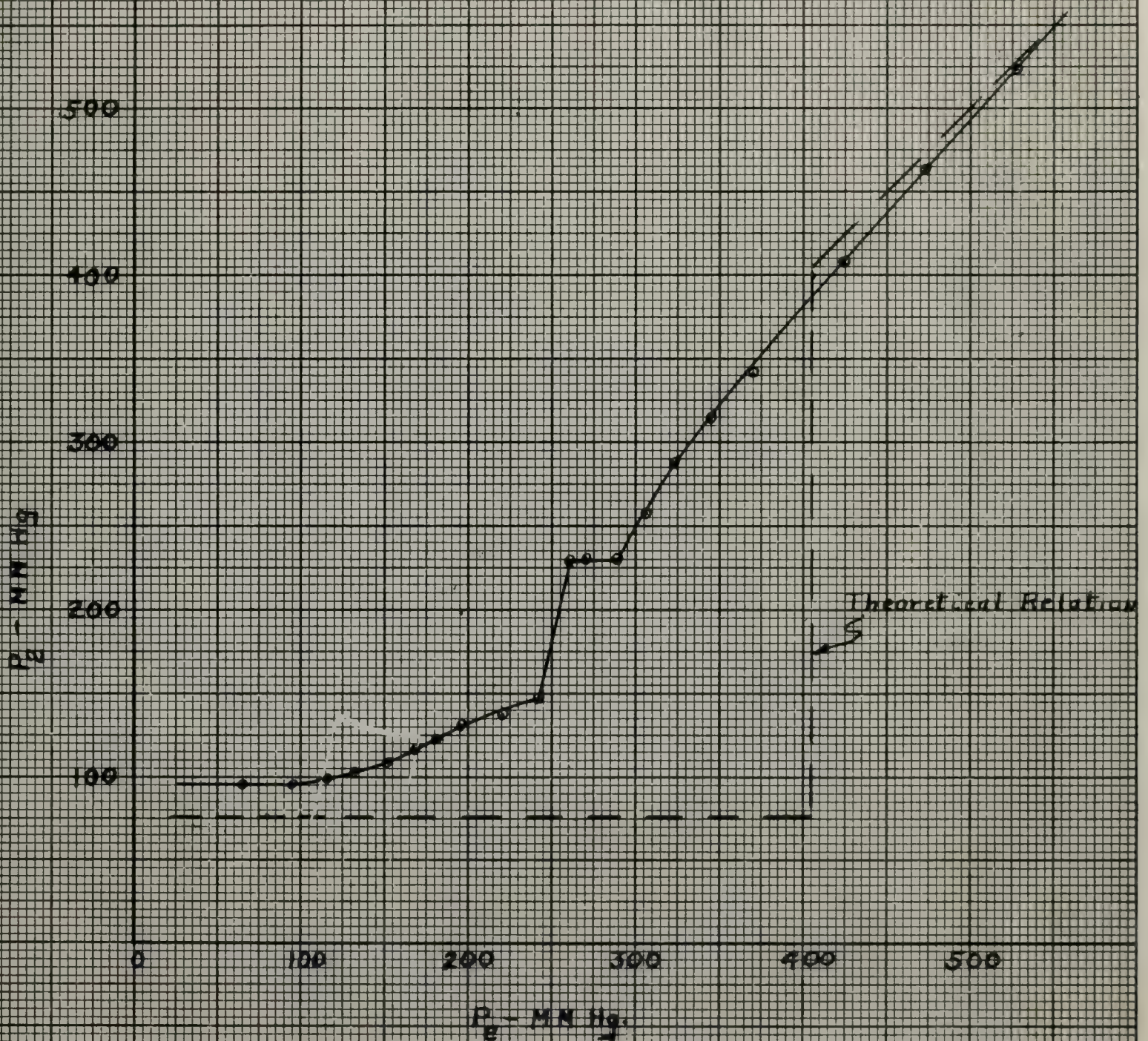


FIGURE II

NOZZLE 2

P_e = EXHAUST PRESSURE

P_2 = PRESSURE IN EXIT.

Nozzle Inlet Pressure 508 mm Hg.

Inlet Temp 85°F

July 15, 1946



FIGURE III

NOZZLE 3

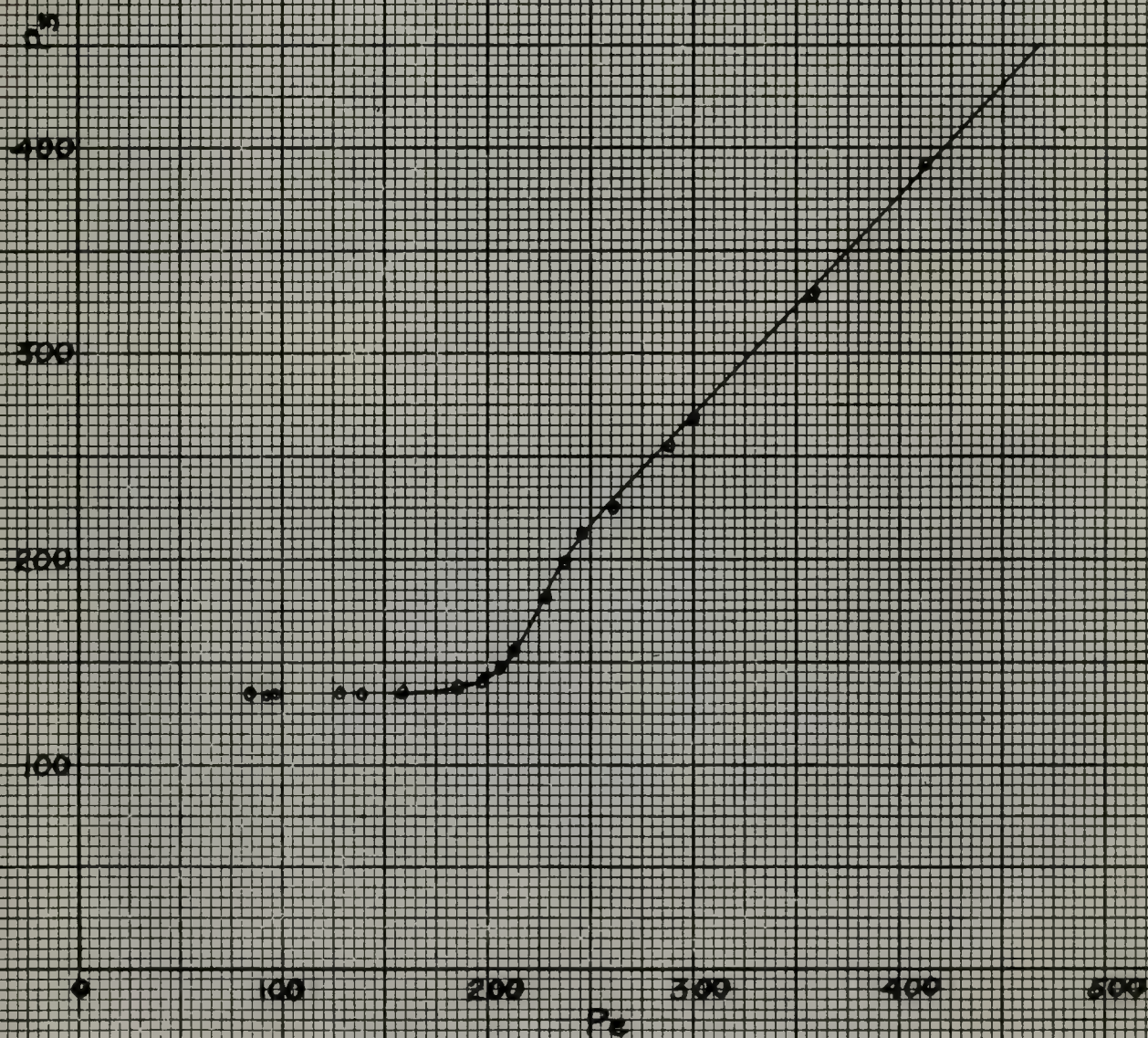
P_e = Exhaust Pressure mm Hg

P_g = Pressure In Exit "

Nozzle Inlet Pressure 764.4 mm Hg

Tube Inlet Pressure 93.4 "

July 22, 1946



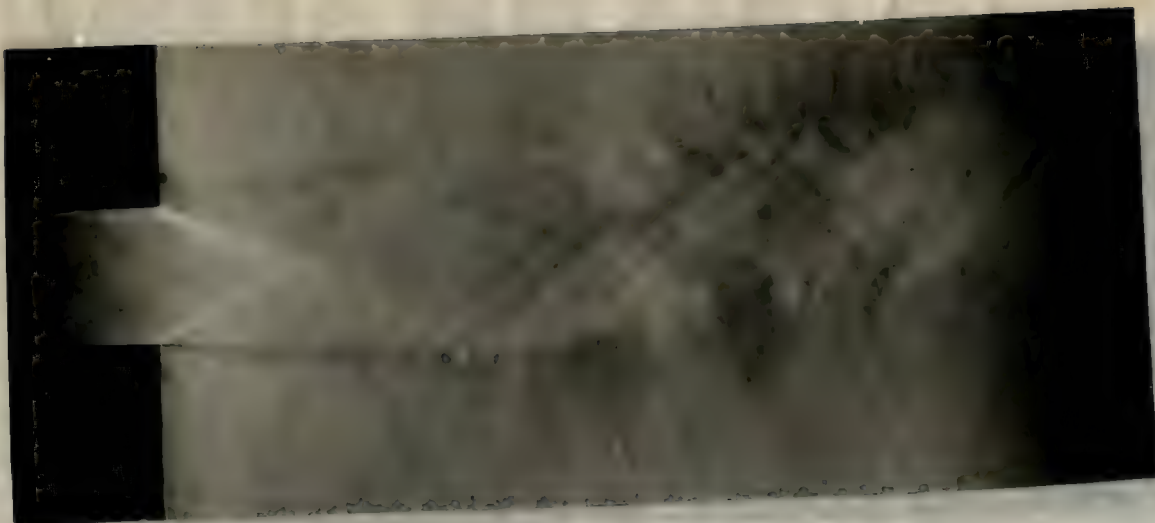


FIGURE IV

Nozzle #1

$P_0 = 74$
 $P_2 = 95$

Flash



FIGURE V

Nozzle #1

$P_0 = 95$
 $P_2 = 95$

Flash

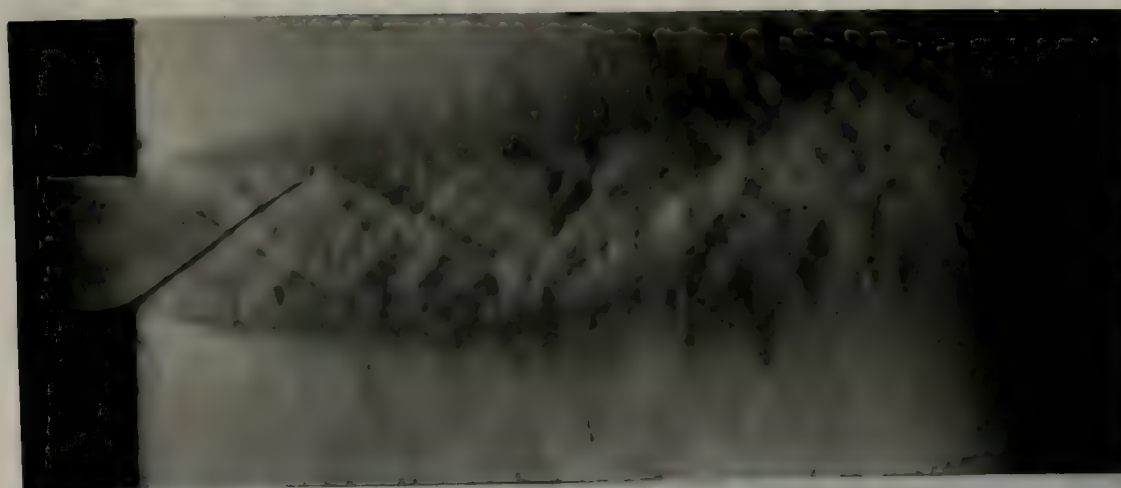


FIGURE VI

Nozzle #1

$P_0 = 111$
 $P_2 = 99$

Flash



FIGURE IV

Nozzle #1

$P_0 = 74$
 $P_2 = 95$

Flash

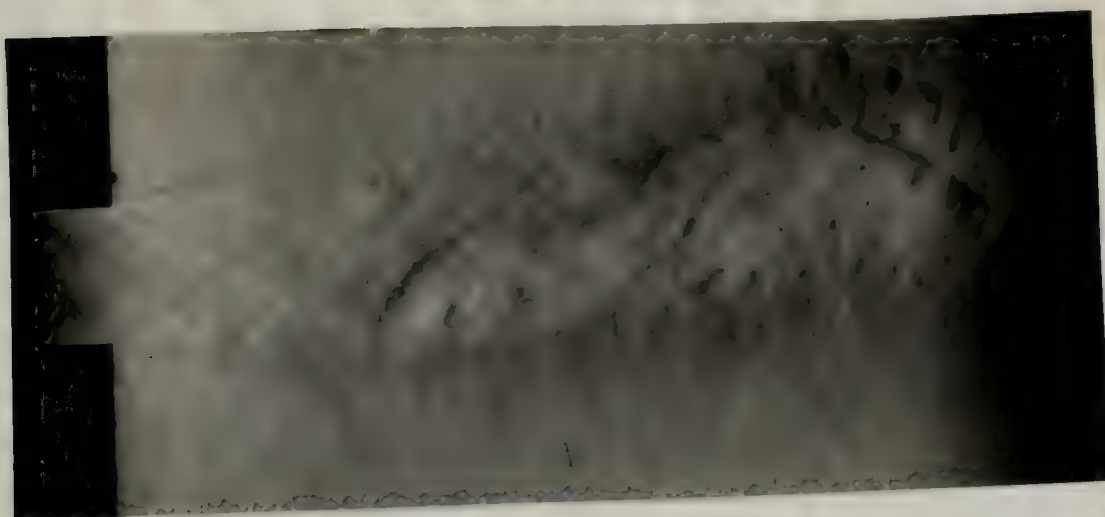


FIGURE V

Nozzle #1

$P_0 = 95$
 $P_2 = 95$

Flash

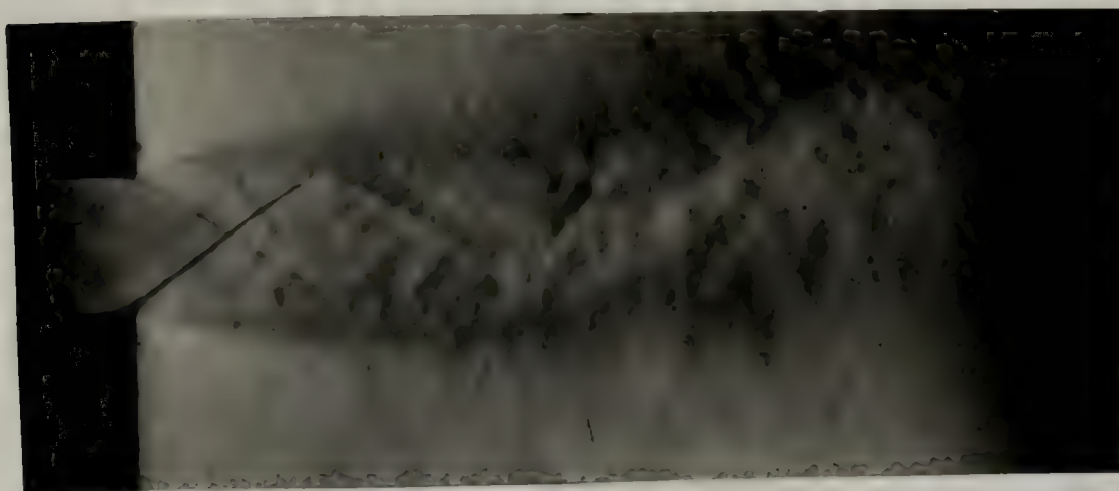


FIGURE VI

Nozzle #1

$P_0 = 111$
 $P_2 = 99$

Flash

100

13

1917

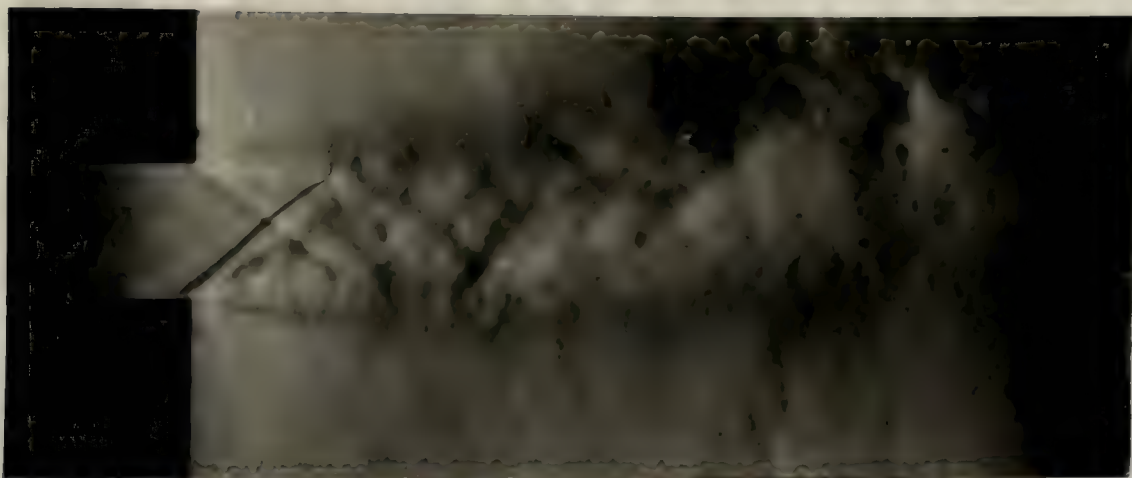


FIGURE VII

Nozzle #1

P_0 - 139
 P_2 - 107

Flash

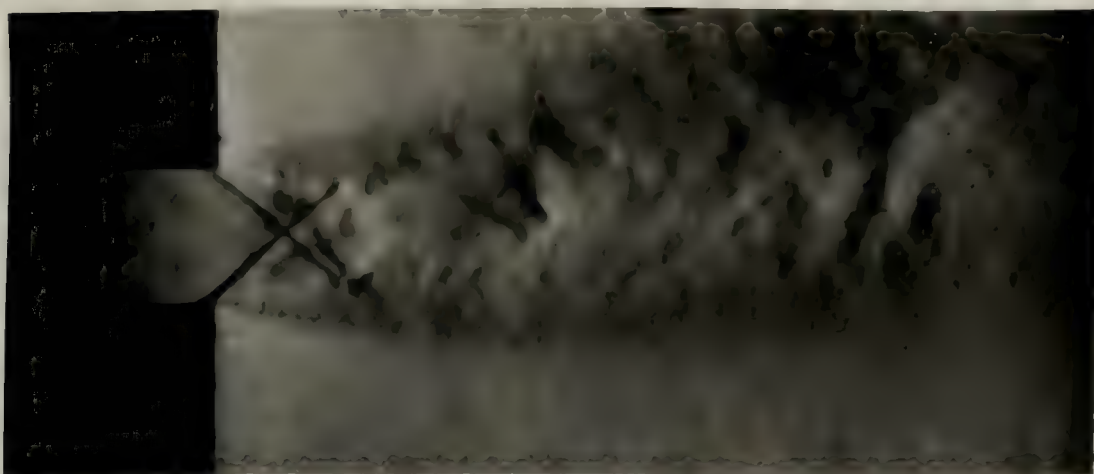


FIGURE VIII

Nozzle #1

P_0 - 171
 P_2 - 117

Flash

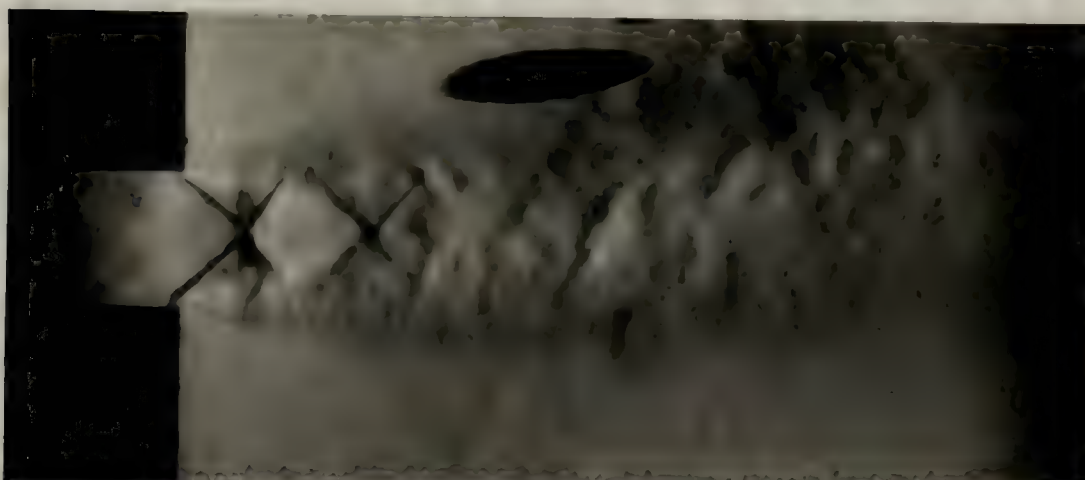


FIGURE IX

Nozzle #1

P_0 - 134
 P_2 - 131

Flash

1. The first part of the paper is devoted to a general discussion of the problem. It is shown that the problem is of great importance in the theory of differential equations.

2. In the second part, we consider the case of a linear differential equation. It is shown that the problem is solvable in this case.

3. In the third part, we consider the case of a nonlinear differential equation. It is shown that the problem is solvable in this case.

4. In the fourth part, we consider the case of a system of differential equations. It is shown that the problem is solvable in this case.

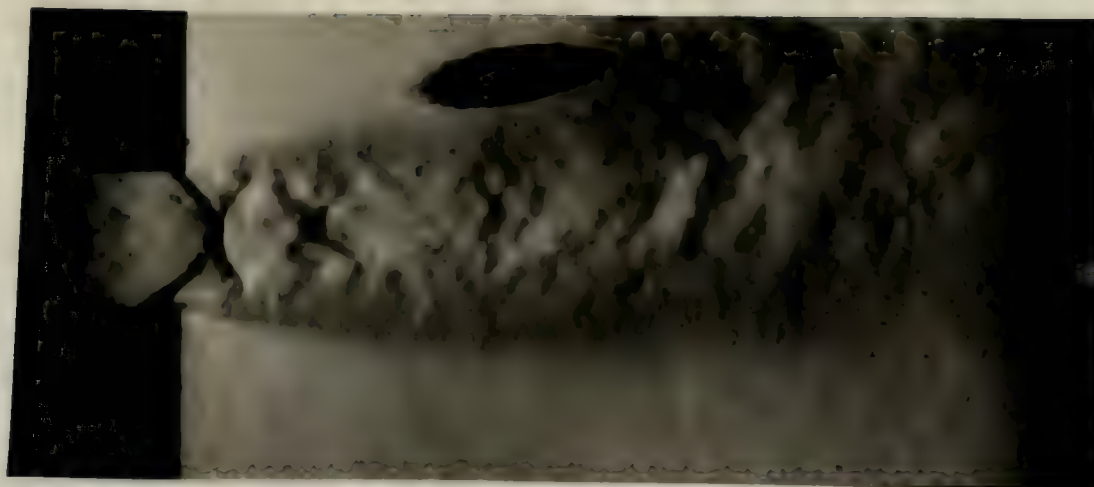


FIGURE X

Nozzle #1

P_0 - 212
 P_2 - 210

Flash

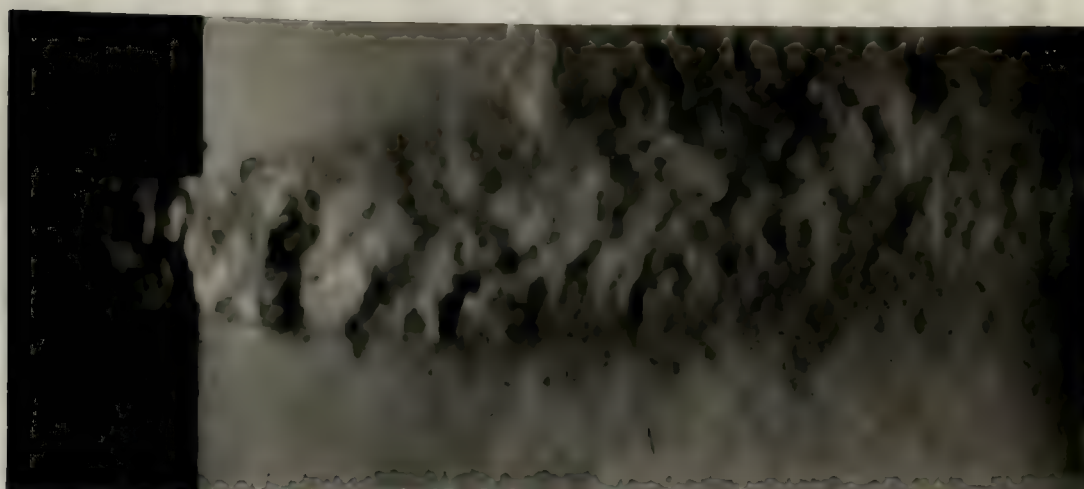


FIGURE XI

Nozzle #1

P_0 - 248
 P_2 - 169

Flash

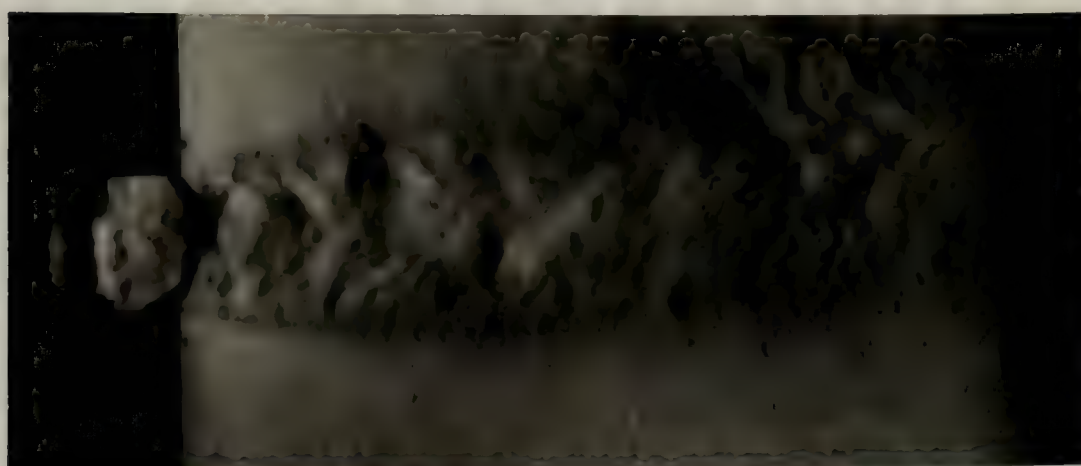


FIGURE XII

Nozzle #1

P_0 - 271
 P_2 - 230

Flash



FIGURE XIII

Sample #1

$P_0 = 343$
 $P_2 = 288$

Flash

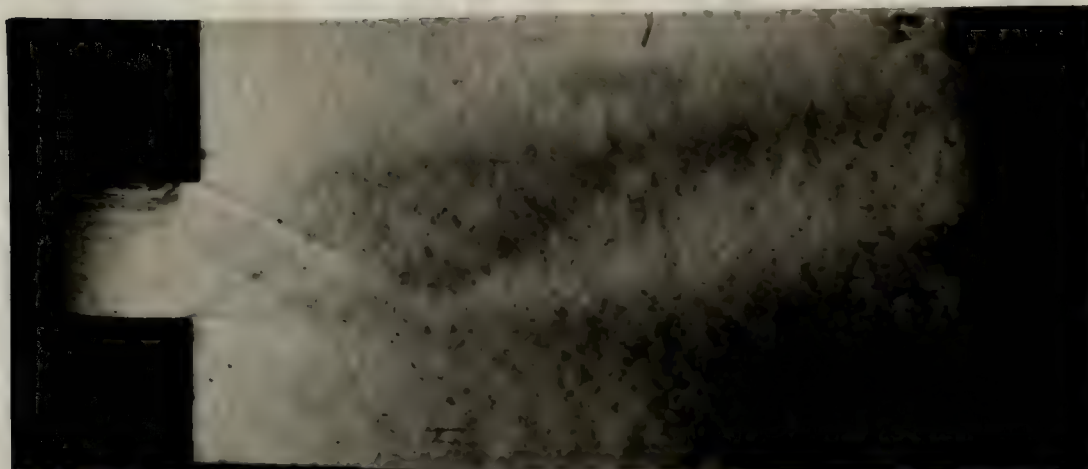


FIGURE XIV

Sample #1

$P_0 = 92$
 $P_2 = 95$

1/80 Sec.

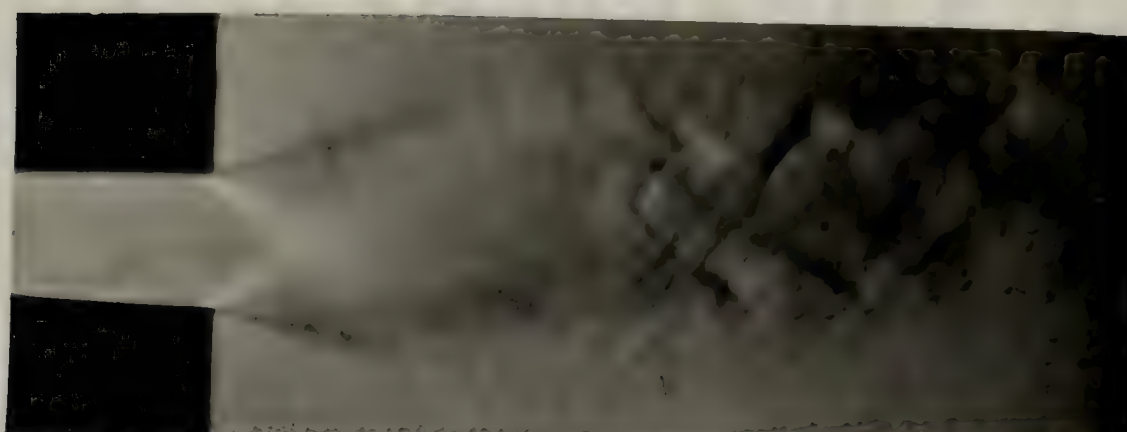


FIGURE XV

Sample #2

$P_0 = 73.59$
 $P_2 = 333.5$
 $P_1 = 303.5$

1/80 Sec.

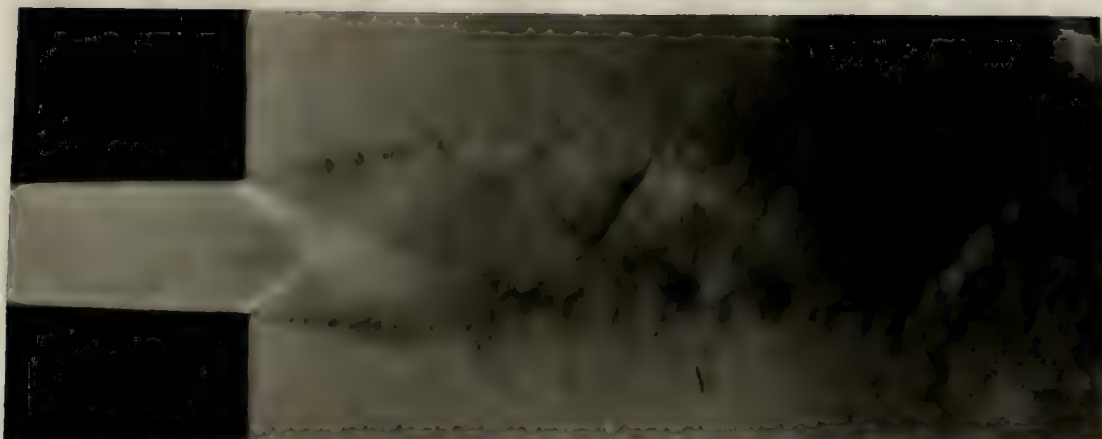


FIGURE XVI

Nozzle #2

$P_e - 94.5$
 $P_2 - 133.5$
 $P_1 - 508.5$

1/80 Sec.

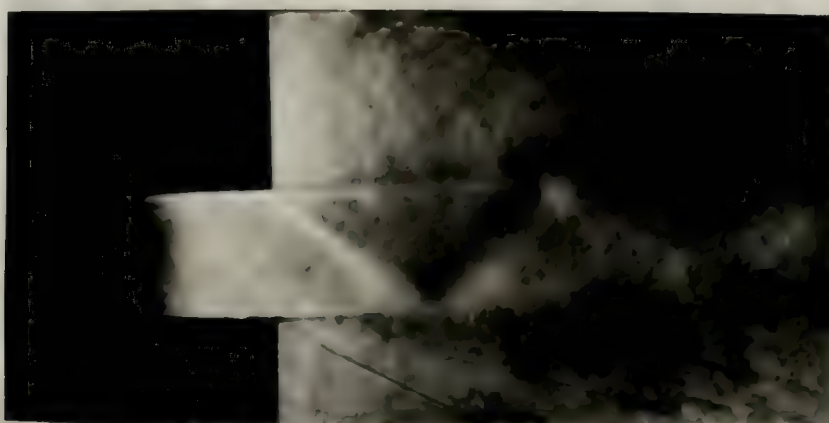


FIGURE XVII

Nozzle #2

$P_e - 132$
 $P_2 - 133$
 $P_1 - 504$

1/80 Sec.

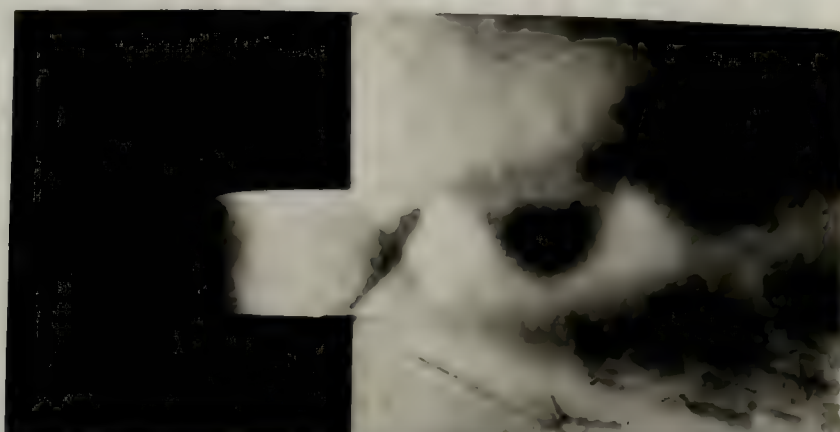


FIGURE XVIII

Nozzle #2

$P_e - 144$
 $P_2 - 138$
 $P_1 - 502$

1/80 Sec.

1900-1901

1901-1902

1902-1903

1903-1904

1904-1905

1905-1906

1906-1907

1907-1908

1908-1909

1909-1910

1910-1911

1911-1912

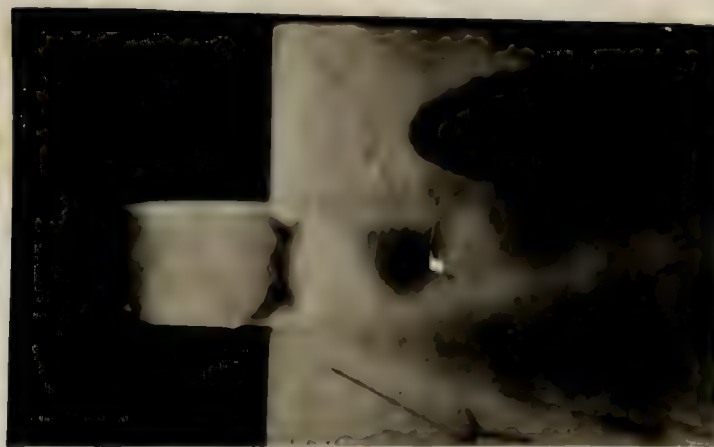


FIGURE XIX

Nozzle #2

P_0 - 192
 P_2 - 155
 P_1 - 504

1/80 Sec.

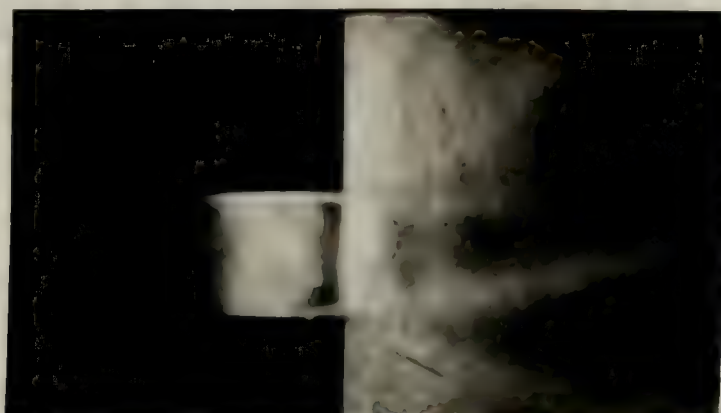


FIGURE XX

Nozzle #2

P_0 - 217
 P_2 - 187
 P_1 - 502

1/80 Sec.

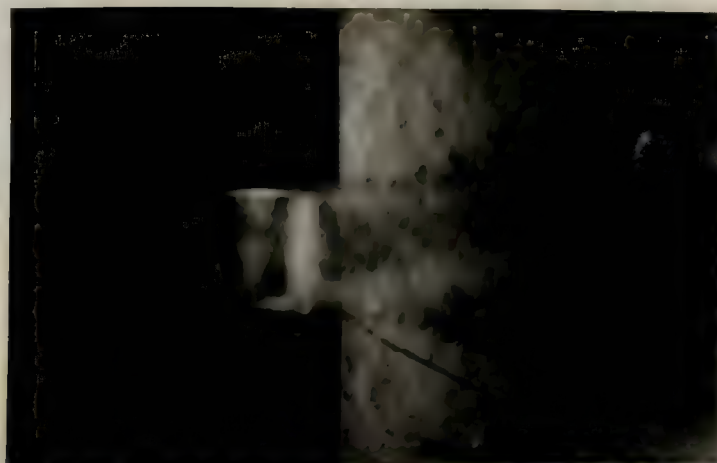


FIGURE XXI

Nozzle #2

P_0 - 235
 P_2 - 217
 P_1 - 501

1/80 Sec.



PLATE III

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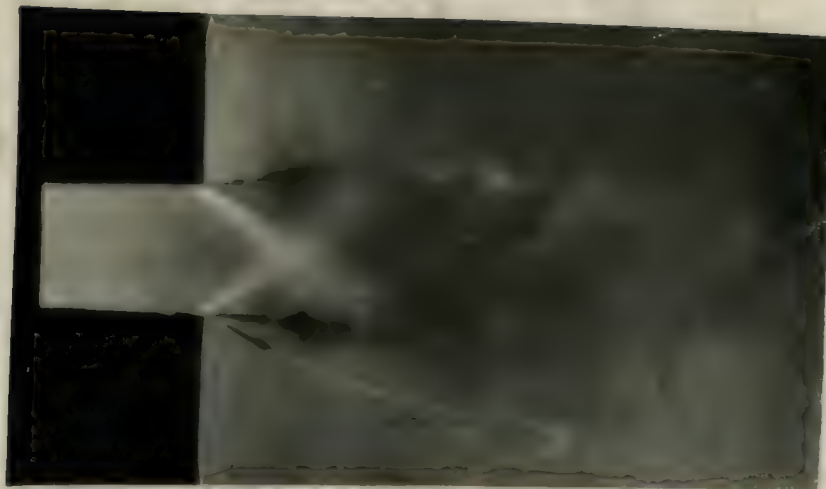


FIGURE XXII

Nozzle #2

P_0 - 98
 P_2 - 130
 P_1 - 509

Flash



FIGURE XXIII

Nozzle #2

P_0 - 131
 P_2 - 131
 P_1 - 508

Flash



FIGURE XXIV

Nozzle #2

P_0 - 146
 P_2 - 145
 P_1 - 508

Flash



1817

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1817



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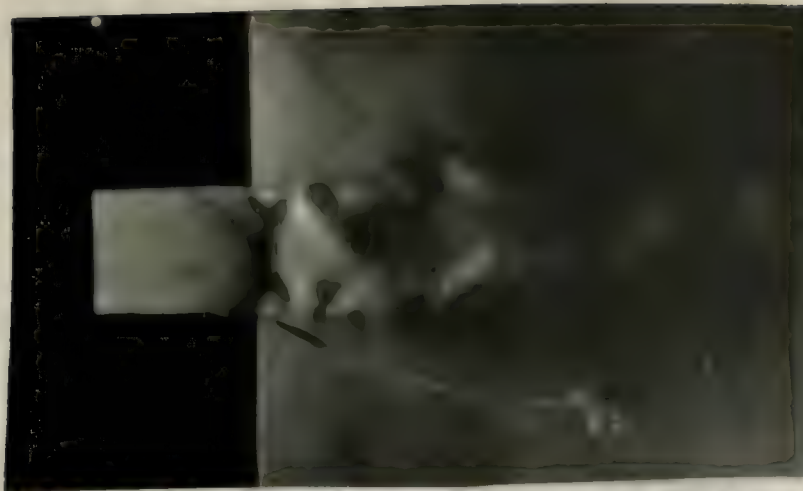


FIGURE XV

Nozzle #2

P_e - 136
P₂ - 148
P₁ - 506

Flash



FIGURE XVI

Nozzle #2

P_e - 219
P₂ - 191
P₁ - 504

Flash



FIGURE XVII

Nozzle #2

P_e - 235
P₂ - 215
P₁ - 504

Flash



1844

1844
1845
1846

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1854



1855

1856
1857
1858

1859

1860

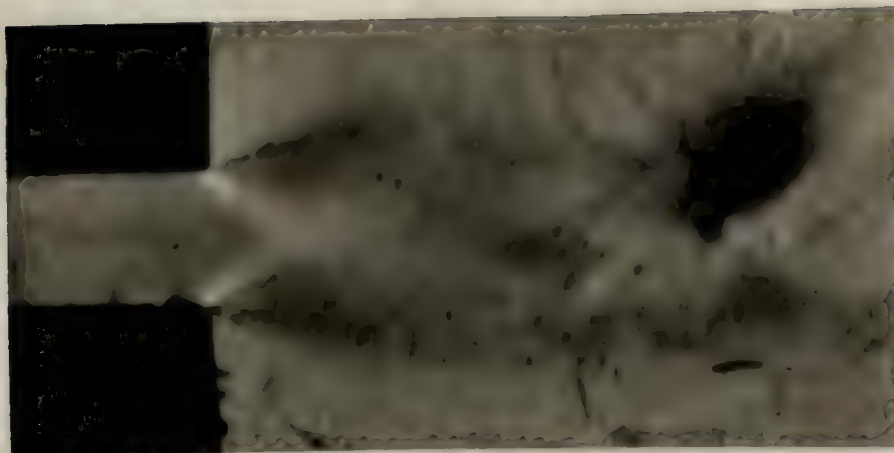


FIGURE XXVIII

Nozzle #3

P_0 - 80.4
 P_3 - 136.4

Flash

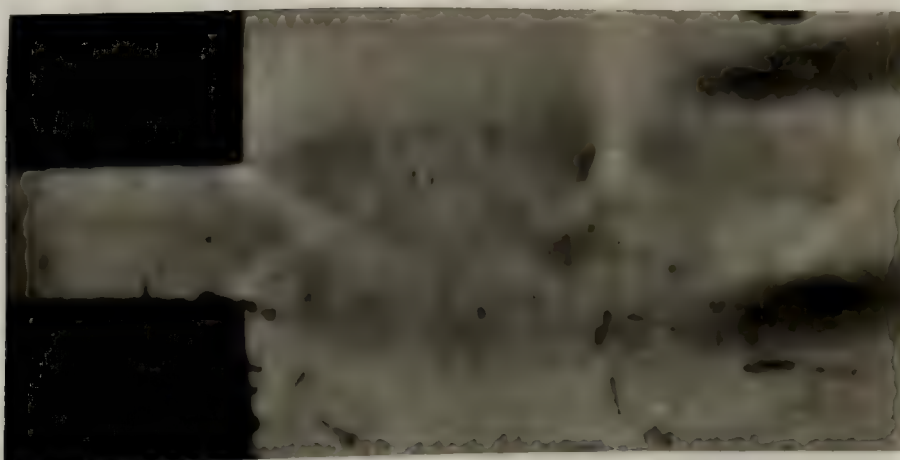


FIGURE XXIX

Nozzle #3

P_0 - 113.4
 P_3 - 136.4

Flash

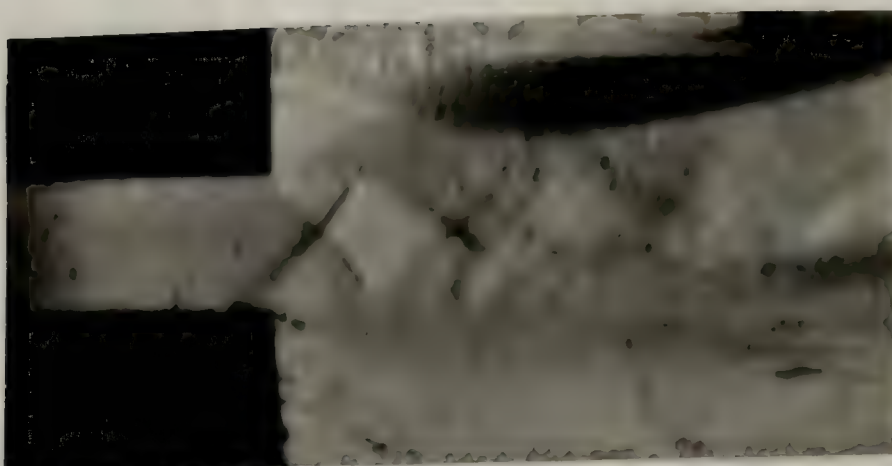


FIGURE XXX

Nozzle #3

P_0 - 172.4
 P_3 - 136.4

Flash



1847

1847 - 1848

1847 - 1848

1847 - 1848



1847

1847 - 1848

1847 - 1848

1847 - 1848



1847

1847 - 1848

1847 - 1848

1847 - 1848

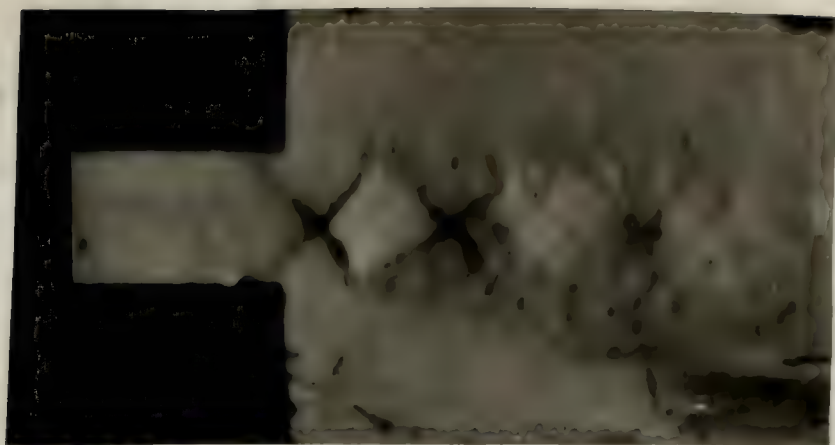


FIGURE XXI

Nozzle #3

$P_e - 197.3$
 $P_3 - 141.4$

Flash

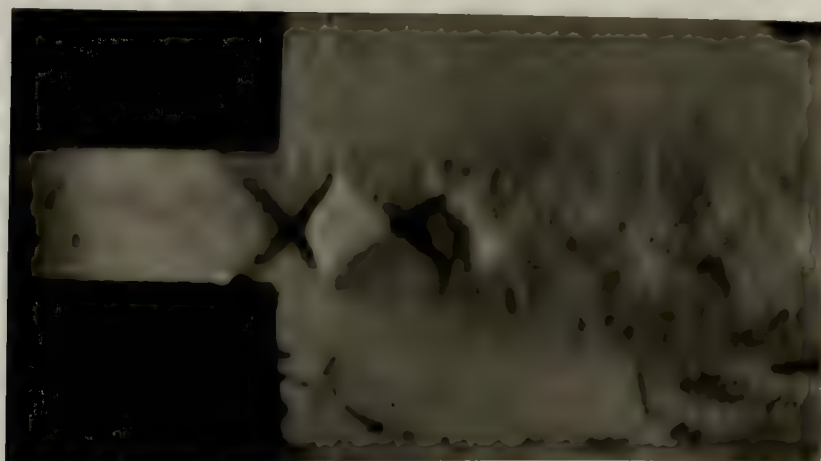


FIGURE XXII

Nozzle #3

$P_e - 213.4$
 $P_3 - 156.4$

Flash

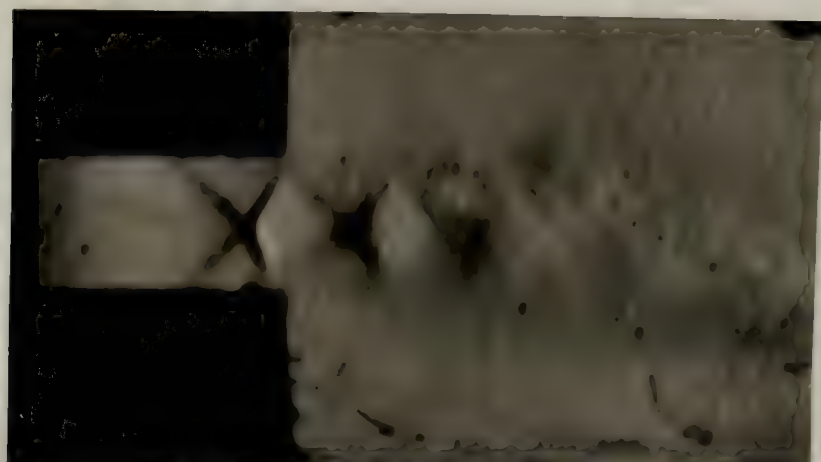


FIGURE XXIII

Nozzle #3

$P_e - 238.4$
 $P_3 - 198.4$

Flash



1780-1785 1785-1790 1790-1795 1795-1800



1800-1805 1805-1810 1810-1815 1815-1820



1820-1825 1825-1830 1830-1835 1835-1840

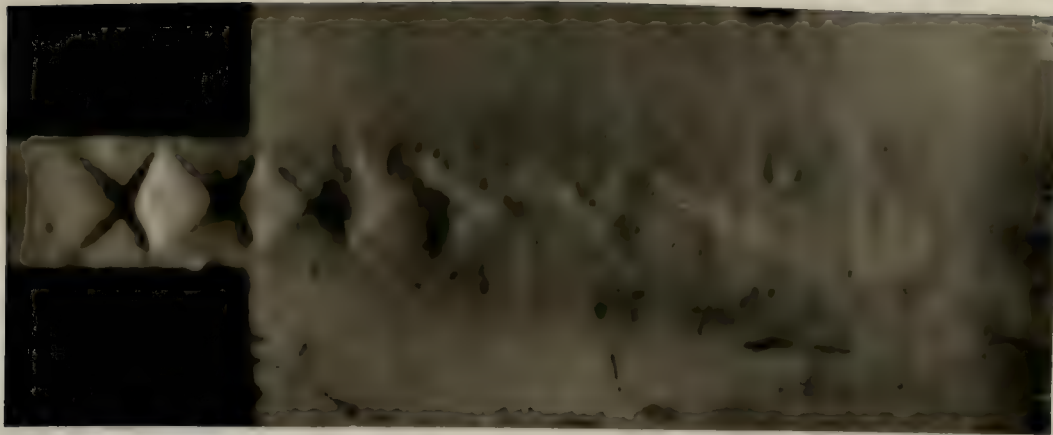


FIGURE XXXIV

Nozzle #3

P_e - 261.4
 P_3 - 225.4

Flash

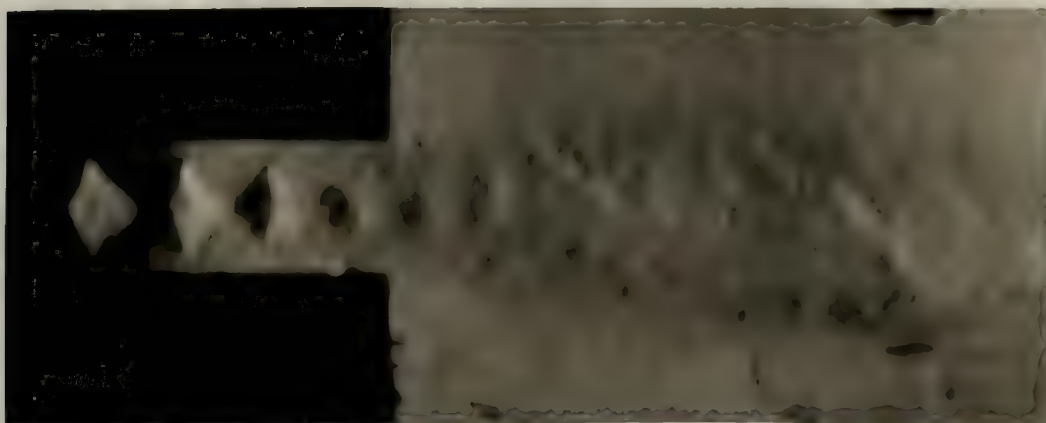


FIGURE XXXV

Nozzle #3

P_e - 300.4
 P_3 - 267.4

Flash

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CONCLUSIONS AND RECOMMENDATIONS

1. Regardless of Mach Number, in supersonic flow the rise of pressure in the exit plane of a practical nozzle is not sudden (in accordance with the theoretical relation) but occurs slowly over a considerable range of exhaust chamber pressure.
2. With thick boundary layer the flow will not support anything resembling a transverse shock.
3. Thickness of boundary layer has the controlling influence on the mechanism by which a supersonic stream adjusts itself to the pressure in the exhaust chamber.
4. It is recommended that further work in this line be carried out with the nozzles mounted parallel to the knife edge of the Schlieren apparatus under the following conditions:
 - (a) Use nozzles #1 and #3 of Appendix B.
 - (b) Use a nozzle with a tube approximately three (3) inches long at a Mach Number of about 1.39 at exit.
 - (c) Use a nozzle with a tube approximately six (6) inches long at a Mach Number of about 1.85 at exit.
5. It is also recommended that investigations of the effect of flow per unit area at the same Mach Number upon the discharge phenomena be carried out.

1. The purpose of this investigation is to determine the effect of the concentration of the solution on the rate of the reaction. The results of the experiment are shown in the following table.
 2. The rate of the reaction was determined by measuring the volume of gas evolved per unit time. The results of the experiment are shown in the following table.
 3. The rate of the reaction was determined by measuring the volume of gas evolved per unit time. The results of the experiment are shown in the following table.
 4. The rate of the reaction was determined by measuring the volume of gas evolved per unit time. The results of the experiment are shown in the following table.
 5. The rate of the reaction was determined by measuring the volume of gas evolved per unit time. The results of the experiment are shown in the following table.
- | Concentration of solution (M) | Rate of reaction (ml/min) |
|-------------------------------|---------------------------|
| 0.1 | 1.2 |
| 0.2 | 2.4 |
| 0.3 | 3.6 |
| 0.4 | 4.8 |
| 0.5 | 6.0 |
- The results of the experiment show that the rate of the reaction increases linearly with the concentration of the solution. This is in agreement with the theoretical prediction that the rate of the reaction is proportional to the concentration of the reactants.
- It is also recommended that further work be done to determine the effect of temperature on the rate of the reaction.
- It is suggested that the following experiment be carried out.

APPENDIX

THE HISTORY OF THE

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THE HISTORY OF THE

THE HISTORY OF THE

APPENDIX A -- DETAILS OF PROCEDURE

Reference (3) illustrates that a good shockless nozzle may be designed by the use of the Prandtl Theory; therefore it was decided to use this method as the basis of the nozzle design. The nozzle design was merely a reproduction of the work of Reference (3) but using different area ratios. A theoretical pressure ratio of .10 was chosen for the basic nozzle (Figure XXVI, Appendix E) with an angle of divergence of $14^{\circ} 15'$. The theoretical Mach number at the exit of this nozzle is 2.152 based on $k = 1.400$. The area ratio is 1.9307. A velocity coefficient of .95 was assumed and the actual Mach number calculated to be 1.85 with a pressure ratio of .124.

It was desired to investigate the effect of Mach number with approximately constant boundary layer thickness on the discharge phenomena. To accomplish this a second nozzle (Figure XXVII, Appendix B) was designed with an area ratio of 1.287. In order to maintain the same flow per unit area at the exit of the two nozzles the inlet pressure in this nozzle was reduced to two thirds ($2/3$) of an atmosphere by a specially designed adjustable fitting (Figure XXIX, Appendix B). With an assumed velocity coefficient of .95, r was calculated as .275 and the Mach number at exit as 1.39. In order to keep both nozzles the same length the angle of divergence was reduced to six (6) degrees. It was believed that any differences that might be caused by this change of angle of divergence would be less than those caused by a change in length which would affect the boundary layer.

In order to observe the effect of boundary layer thickness

[illegible]

on the discharge phenomena for the same Mach number at exit, it was decided to add to the basic nozzle (Nozzle 1) a straight constant area section of such length as to reduce the Mach number of Nozzle #1 (1.85) to the Mach number of Nozzle #2 (1.34). To eliminate the possibility of shock formation at the junction of the nozzle and tube it was decided to fabricate another nozzle with the straight portion integral with the nozzle itself (Figure XIXVIII). By use of data obtained from Reference (6) the length of tube necessary was calculated to be 10.35 inches. This figure was regarded as highly approximate due to the use of a two dimensional tube instead of the circular section upon which the data of Reference (6) is based.

Provision was made for pressure measurement by mercury manometer at a point one eighth ($1/8$) inch from the nozzle or tube exit and in the discharge chamber of all nozzles by a .020 inch diameter hole in the steel contour.

All pictures were taken with the axis of the nozzle perpendicular to the knife edge of the Schlieren apparatus described adequately in Reference (1).

The pictures designated "Flash" were made by using the Edgerton Flash Unit also described in Reference (1). This gave an exposure time of approximately $.5 \times 10^{-6}$ seconds. A few pictures were taken using a steady light source and an exposure time of $1/80$ seconds, to show the difference in detail of pictures obtained by the use of the two different methods.

on the straight segments for the same value of α , it was
found to be in the form $\alpha = 1.5$ (see Table I) a straight segment
also being at $\alpha = 1.5$ as to show the fact that the value of
(1.5) is the same for all values of α . To illustrate the
possibility of such a result as the position of the curve and the
it was found to be a straight segment with a slope of 1.5
intercept with the curve itself (Figure XXVIII). By use of data
obtained from Figure 10, the value of α was determined and
to be 1.5. This value was determined by the use of the
to the use of a straight line instead of the circular section upon
which the data in Figure 10 is based.
Provided we use the present treatment for the present
of a curve and Figure 10, then the value of α will not
be the straight segment of all values of α and the value of
is the same.
All values of α will be the same as the value of the straight
to the value of the straight segment of the curve.
is Figure 11.
The straight segment of the curve will be the same as the
Figure 11 also shows the straight segment of the curve.
line of approximately $\alpha = 1.5$ and the straight segment of
with a slope of 1.5 and the straight segment of the curve.
to show the straight segment of the curve and the straight
the straight segment.

APPENDIX B---EXPERIMENTAL DATA

TABLE I

PRESSURE READINGS, NOZZLE I

19 JULY, 1946

P_e = Exhaust Chamber Pressure, mm. Hg.

P_2 = Pressure in Exit of Nozzle, mm. Hg.

P_a = Nozzle Inlet Pressure, Atmospheric

T_1 = Inlet Temperature, Degrees F.

P_e	P_2	P_a	T_1
74	95	761.2	85
95	95		
116	99		
133	104		
153	109		
169	116		
181	122		
196	131		
220	136		
241	197		
260	228		
287	230		
324	289		
370	341		
424	407		
473	464		
527	520		

THE JOURNAL OF THE

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1912, 1913, 1914

1915, 1916, 1917

1918, 1919, 1920

1921, 1922, 1923

1924, 1925, 1926

1927, 1928, 1929

1930, 1931, 1932

1933, 1934, 1935

1936, 1937, 1938

1939, 1940, 1941

1942, 1943, 1944

1945, 1946, 1947

1948, 1949, 1950

1951, 1952, 1953

1954, 1955, 1956

1957, 1958, 1959

1960, 1961, 1962

TABLE II

PRESSURE READINGS, NOZZLE # 2

13 JULY, 1946

 P_e = Exhaust Chamber Pressure, mm. Hg. P_2 = Pressure in Exit of Nozzle, mm. Hg. P_1 = Nozzle Inlet Pressure, mm. Hg. P_a = Atmospheric Pressure, mm. Hg. T_1 = Nozzle Inlet Temperature, Degrees F.

P_e	P_2	P_1	P_a	T_1
71	133	502	761.5	85
86	133	502		
94	133	502		
113	133	502		
131	133	502		
144	138	502		
151	143	502		
171	146	502		
183	150	502		
192	155	502		
211	178	502		
217	188	502		
244	227	502		
296	288	502		
340	338	502		
418	417	502		

5. *Journal of the American Medical Association*, 1990; 263: 1025-1026.

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TABLE III

PRESSURE READINGS, NOZZLE #3

22 JULY, 1946

P_e = Exhaust Chamber Pressure, mm. Hg.

P_3 = Pressure at Exit of Tube, mm. Hg.

P_2 = Pressure at Tube Inlet (Nozzle Exit), mm. Hg.

P_a = Nozzle Inlet Pressure, Atmospheric

T_1 = Inlet Temperature, Degrees F.

P_e	P_3	P_2	P_a	T_1
<u> </u>	<u> </u>	<u> </u>	<u> </u>	<u> </u>
80.4	135.4	93.4	764.4	85
97	135			
113	135			
129	135			
140	135			
158	135			
185	137			
197	141			
206	148			
213	156			
228	181			
238	198			
246	213			
261	225			
288	255			
300	267			
358	229			

TABLE III

TABLE III

TABLE III

TABLE III

TABLE III

TABLE III

TABLE III

TABLE III

$\frac{1}{\lambda}$	$\frac{1}{\lambda}$	$\frac{1}{\lambda}$	$\frac{1}{\lambda}$	$\frac{1}{\lambda}$
1.00	1.00	1.00	1.00	1.00
1.01	1.01	1.01	1.01	1.01
1.02	1.02	1.02	1.02	1.02
1.03	1.03	1.03	1.03	1.03
1.04	1.04	1.04	1.04	1.04
1.05	1.05	1.05	1.05	1.05
1.06	1.06	1.06	1.06	1.06
1.07	1.07	1.07	1.07	1.07
1.08	1.08	1.08	1.08	1.08
1.09	1.09	1.09	1.09	1.09
1.10	1.10	1.10	1.10	1.10
1.11	1.11	1.11	1.11	1.11
1.12	1.12	1.12	1.12	1.12
1.13	1.13	1.13	1.13	1.13
1.14	1.14	1.14	1.14	1.14
1.15	1.15	1.15	1.15	1.15
1.16	1.16	1.16	1.16	1.16
1.17	1.17	1.17	1.17	1.17
1.18	1.18	1.18	1.18	1.18
1.19	1.19	1.19	1.19	1.19
1.20	1.20	1.20	1.20	1.20
1.21	1.21	1.21	1.21	1.21
1.22	1.22	1.22	1.22	1.22
1.23	1.23	1.23	1.23	1.23
1.24	1.24	1.24	1.24	1.24
1.25	1.25	1.25	1.25	1.25
1.26	1.26	1.26	1.26	1.26
1.27	1.27	1.27	1.27	1.27
1.28	1.28	1.28	1.28	1.28
1.29	1.29	1.29	1.29	1.29
1.30	1.30	1.30	1.30	1.30
1.31	1.31	1.31	1.31	1.31
1.32	1.32	1.32	1.32	1.32
1.33	1.33	1.33	1.33	1.33
1.34	1.34	1.34	1.34	1.34
1.35	1.35	1.35	1.35	1.35
1.36	1.36	1.36	1.36	1.36
1.37	1.37	1.37	1.37	1.37
1.38	1.38	1.38	1.38	1.38
1.39	1.39	1.39	1.39	1.39
1.40	1.40	1.40	1.40	1.40
1.41	1.41	1.41	1.41	1.41
1.42	1.42	1.42	1.42	1.42
1.43	1.43	1.43	1.43	1.43
1.44	1.44	1.44	1.44	1.44
1.45	1.45	1.45	1.45	1.45
1.46	1.46	1.46	1.46	1.46
1.47	1.47	1.47	1.47	1.47
1.48	1.48	1.48	1.48	1.48
1.49	1.49	1.49	1.49	1.49
1.50	1.50	1.50	1.50	1.50

TABLE IV

NOZZLE CHARACTERISTICS

A_t = Cross-sectional Area at Throat

A_e = Cross-sectional Area at Exit

r_t = Theoretical Ratio of Exit Pressure to Inlet Pressure

r_a = Actual Ratio of Exit Pressure to Inlet Pressure

M_t = Theoretical Mach Number at Exit (Frictionless Flow)

M_a = Actual Mach Number at Exit

C_v = Assumed Velocity Coefficient

w = Flow in Pounds per Second

G = Flow per Unit Area at Exit, Pounds per Squarefoot per Second

T_1 = Inlet Temperature, Degrees F.

P_1 = Inlet Pressure, Atmospheres

<u>NOTATION</u>	<u>NOZZLE # 1</u>	<u>NOZZLE # 2</u>	<u>NOZZLE # 3</u>
A_t/A_e	1.9307	1.2870	1.9307
r_t	.1000	.2200	.1000
r_a	.1240	.2750	.1833
M_t	2.1520	1.6180	2.1520
M_a	1.8500	1.3900	1.3900
C_v	.95	.95	
P_1	1.0000	.6667	1.0000
T_1	85	85	85
w	.0676	.0676	.0676
G	25.2000	25.2000	25.2000

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1. 2. 3. 4. 5. 6. 7. 8. 9. 10. 11. 12. 13. 14. 15. 16. 17. 18. 19. 20. 21. 22. 23. 24. 25. 26. 27. 28. 29. 30. 31. 32. 33. 34. 35. 36. 37. 38. 39. 40. 41. 42. 43. 44. 45. 46. 47. 48. 49. 50. 51. 52. 53. 54. 55. 56. 57. 58. 59. 60. 61. 62. 63. 64. 65. 66. 67. 68. 69. 70. 71. 72. 73. 74. 75. 76. 77. 78. 79. 80. 81. 82. 83. 84. 85. 86. 87. 88. 89. 90. 91. 92. 93. 94. 95. 96. 97. 98. 99. 100. 101. 102. 103. 104. 105. 106. 107. 108. 109. 110. 111. 112. 113. 114. 115. 116. 117. 118. 119. 120. 121. 122. 123. 124. 125. 126. 127. 128. 129. 130. 131. 132. 133. 134. 135. 136. 137. 138. 139. 140. 141. 142. 143. 144. 145. 146. 147. 148. 149. 150. 151. 152. 153. 154. 155. 156. 157. 158. 159. 160. 161. 162. 163. 164. 165. 166. 167. 168. 169. 170. 171. 172. 173. 174. 175. 176. 177. 178. 179. 180. 181. 182. 183. 184. 185. 186. 187. 188. 189. 190. 191. 192. 193. 194. 195. 196. 197. 198. 199. 200. 201. 202. 203. 204. 205. 206. 207. 208. 209. 210. 211. 212. 213. 214. 215. 216. 217. 218. 219. 220. 221. 222. 223. 224. 225. 226. 227. 228. 229. 230. 231. 232. 233. 234. 235. 236. 237. 238. 239. 240. 241. 242. 243. 244. 245. 246. 247. 248. 249. 250. 251. 252. 253. 254. 255. 256. 257. 258. 259. 260. 261. 262. 263. 264. 265. 266. 267. 268. 269. 270. 271. 272. 273. 274. 275. 276. 277. 278. 279. 280. 281. 282. 283. 284. 285. 286. 287. 288. 289. 290. 291. 292. 293. 294. 295. 296. 297. 298. 299. 300. 301. 302. 303. 304. 305. 306. 307. 308. 309. 310. 311. 312. 313. 314. 315. 316. 317. 318. 319. 320. 321. 322. 323. 324. 325. 326. 327. 328. 329. 330. 331. 332. 333. 334. 335. 336. 337. 338. 339. 340. 341. 342. 343. 344. 345. 346. 347. 348. 349. 350. 351. 352. 353. 354. 355. 356. 357. 358. 359. 360. 361. 362. 363. 364. 365. 366. 367. 368. 369. 370. 371. 372. 373. 374. 375. 376. 377. 378. 379. 380. 381. 382. 383. 384. 385. 386. 387. 388. 389. 390. 391. 392. 393. 394. 395. 396. 397. 398. 399. 400. 401. 402. 403. 404. 405. 406. 407. 408. 409. 410. 411. 412. 413. 414. 415. 416. 417. 418. 419. 420. 421. 422. 423. 424. 425. 426. 427. 428. 429. 430. 431. 432. 433. 434. 435. 436. 437. 438. 439. 440. 441. 442. 443. 444. 445. 446. 447. 448. 449. 450. 451. 452. 453. 454. 455. 456. 457. 458. 459. 460. 461. 462. 463. 464. 465. 466. 467. 468. 469. 470. 471. 472. 473. 474. 475. 476. 477. 478. 479. 480. 481. 482. 483. 484. 485. 486. 487. 488. 489. 490. 491. 492. 493. 494. 495. 496. 497. 498. 499. 500. 501. 502. 503. 504. 505. 506. 507. 508. 509. 510. 511. 512. 513. 514. 515. 516. 517. 518. 519. 520. 521. 522. 523. 524. 525. 526. 527. 528. 529. 530. 531. 532. 533. 534. 535. 536. 537. 538. 539. 540. 541. 542. 543. 544. 545. 546. 547. 548. 549. 550. 551. 552. 553. 554. 555. 556. 557. 558. 559. 560. 561. 562. 563. 564. 565. 566. 567. 568. 569. 570. 571. 572. 573. 574. 575. 576. 577. 578. 579. 580. 581. 582. 583. 584. 585. 586. 587. 588. 589. 590. 591. 592. 593. 594. 595. 596. 597. 598. 599. 600. 601. 602. 603. 604. 605. 606. 607. 608. 609. 610. 611. 612. 613. 614. 615. 616. 617. 618. 619. 620. 621. 622. 623. 624. 625. 626. 627. 628. 629. 630. 631. 632. 633. 634. 635. 636. 637. 638. 639. 640. 641. 642. 643. 644. 645. 646. 647. 648. 649. 650. 651. 652. 653. 654. 655. 656. 657. 658. 659. 660. 661. 662. 663. 664. 665. 666. 667. 668. 669. 670. 671. 672. 673. 674. 675. 676. 677. 678. 679. 680. 681. 682. 683. 684. 685. 686. 687. 688. 689. 690. 691. 692. 693. 694. 695. 696. 697. 698. 699. 700. 701. 702. 703. 704. 705. 706. 707. 708. 709. 710. 711. 712. 713. 714. 715. 716. 717. 718. 719. 720. 721. 722. 723. 724. 725. 726. 727. 728. 729. 730. 731. 732. 733. 734. 735. 736. 737. 738. 739. 740. 741. 742. 743. 744. 745. 746. 747. 748. 749. 750. 751. 752. 753. 754. 755. 756. 757. 758. 759. 760. 761. 762. 763. 764. 765. 766. 767. 768. 769. 770. 771. 772. 773. 774. 775. 776. 777. 778. 779. 780. 781. 782. 783. 784. 785. 786. 787. 788. 789. 790. 791. 792. 793. 794. 795. 796. 797. 798. 799. 800. 801. 802. 803. 804. 805. 806. 807. 808. 809. 810. 811. 812. 813. 814. 815. 816. 817. 818. 819. 820. 821. 822. 823. 824. 825. 826. 827. 828. 829. 830. 831. 832. 833. 834. 835. 836. 837. 838. 839. 840. 84

1. The first part of the paper is devoted to the study of the properties of the function $f(x)$ defined by the equation

[illegible]

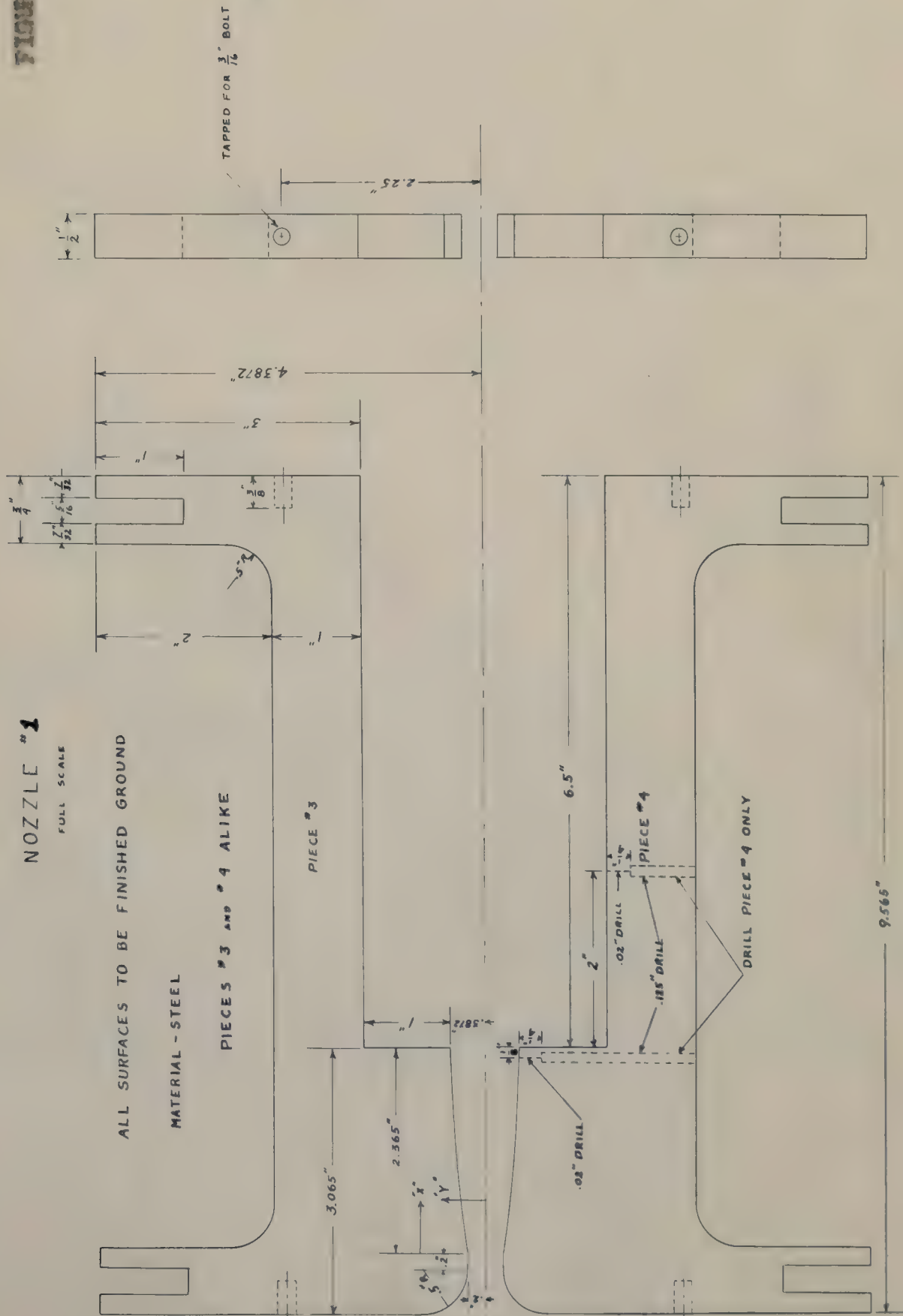
FIGURE XXXVI

NOZZLE #1
FULL SCALE

ALL SURFACES TO BE FINISHED GROUND

MATERIAL - STEEL

PIECES #3 AND #4 ALIKE



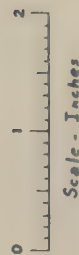
OFFSETS NOZZLE #1

| "X" | "Y" |
|-------|-------|
| 0 | .2000 |
| .87 | .3100 |
| .95 | .3200 |
| 1.00 | .3250 |
| 1.10 | .3360 |
| 1.20 | .3470 |
| 1.30 | .3550 |
| 1.40 | .3635 |
| 1.50 | .3640 |
| 1.60 | .3740 |
| 1.70 | .3790 |
| 1.80 | .3830 |
| 1.90 | .3850 |
| 2.00 | .3860 |
| 2.10 | .3865 |
| 2.20 | .3870 |
| 2.24 | .3872 |
| 2.365 | .3872 |

STRAIGHT SLOPE

CURVED PORT

ST. HORIZ. PORT



PIECE XXVII

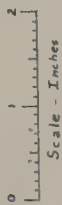
OFFSETS NOZZLE 2

| X" | Y" |
|------|------|
| 0 | 5000 |
| 1.00 | 5500 |
| 1.20 | 5580 |
| 1.40 | 5600 |
| 1.60 | 5675 |
| 1.80 | 5710 |
| 2.00 | 5742 |
| 2.20 | 5775 |
| 2.40 | 5800 |
| 2.60 | 5825 |
| 2.80 | 5850 |
| 3.00 | 5870 |
| 3.20 | 5872 |

STRAIGHT SLOPING

CURVED PORTION

ST HORIZ PORTION



NOZZLE 2
FULL SCALE

ALL SURFACES TO BE FINISHED GROUND

MATERIAL - STEEL

PIECES #5 AND #6 ALIKE

PIECE #5

PIECE #6

DRILL PIECE #6 ONLY

OFFSETS NOZZLE "3"

| STRAIGHT SLOPING | | CURVED PORTION | | ST. HORIZ. PORTION | |
|------------------|----------|----------------|----------|--------------------|----------|
| α | α | α | α | α | α |
| 0 | 2.000 | 1.40 | 2.600 | 2.20 | 3.870 |
| 87 | 31.00 | 1.60 | 3.740 | 2.24 | 3.872 |
| 95 | 32.00 | 1.70 | 3.790 | 2.365 | |
| 1.00 | 33.50 | 1.80 | 3.830 | 2.50 | 3.860 |
| 1.10 | 34.60 | 1.90 | 3.870 | 2.70 | 3.865 |
| 1.20 | 34.70 | 2.00 | 3.900 | 2.80 | 3.870 |
| 1.30 | 34.85 | 2.10 | 3.930 | 2.90 | 3.872 |
| 1.40 | 34.95 | 2.20 | 3.960 | 3.00 | 3.872 |
| 1.50 | 35.00 | 2.30 | 3.990 | 3.10 | 3.872 |
| 1.60 | 35.00 | 2.40 | 4.020 | 3.20 | 3.872 |
| 1.70 | 35.00 | 2.50 | 4.050 | 3.30 | 3.872 |
| 1.80 | 35.00 | 2.60 | 4.080 | 3.40 | 3.872 |
| 1.90 | 35.00 | 2.70 | 4.110 | 3.50 | 3.872 |
| 2.00 | 35.00 | 2.80 | 4.140 | 3.60 | 3.872 |
| 2.10 | 35.00 | 2.90 | 4.170 | 3.70 | 3.872 |
| 2.20 | 35.00 | 3.00 | 4.200 | 3.80 | 3.872 |
| 2.30 | 35.00 | 3.10 | 4.230 | 3.90 | 3.872 |
| 2.40 | 35.00 | 3.20 | 4.260 | 4.00 | 3.872 |
| 2.50 | 35.00 | 3.30 | 4.290 | 4.10 | 3.872 |
| 2.60 | 35.00 | 3.40 | 4.320 | 4.20 | 3.872 |
| 2.70 | 35.00 | 3.50 | 4.350 | 4.30 | 3.872 |
| 2.80 | 35.00 | 3.60 | 4.380 | 4.40 | 3.872 |
| 2.90 | 35.00 | 3.70 | 4.410 | 4.50 | 3.872 |
| 3.00 | 35.00 | 3.80 | 4.440 | 4.60 | 3.872 |
| 3.10 | 35.00 | 3.90 | 4.470 | 4.70 | 3.872 |
| 3.20 | 35.00 | 4.00 | 4.500 | 4.80 | 3.872 |
| 3.30 | 35.00 | 4.10 | 4.530 | 4.90 | 3.872 |
| 3.40 | 35.00 | 4.20 | 4.560 | 5.00 | 3.872 |
| 3.50 | 35.00 | 4.30 | 4.590 | 5.10 | 3.872 |
| 3.60 | 35.00 | 4.40 | 4.620 | 5.20 | 3.872 |
| 3.70 | 35.00 | 4.50 | 4.650 | 5.30 | 3.872 |
| 3.80 | 35.00 | 4.60 | 4.680 | 5.40 | 3.872 |
| 3.90 | 35.00 | 4.70 | 4.710 | 5.50 | 3.872 |
| 4.00 | 35.00 | 4.80 | 4.740 | 5.60 | 3.872 |
| 4.10 | 35.00 | 4.90 | 4.770 | 5.70 | 3.872 |
| 4.20 | 35.00 | 5.00 | 4.800 | 5.80 | 3.872 |
| 4.30 | 35.00 | 5.10 | 4.830 | 5.90 | 3.872 |
| 4.40 | 35.00 | 5.20 | 4.860 | 6.00 | 3.872 |
| 4.50 | 35.00 | 5.30 | 4.890 | 6.10 | 3.872 |
| 4.60 | 35.00 | 5.40 | 4.920 | 6.20 | 3.872 |
| 4.70 | 35.00 | 5.50 | 4.950 | 6.30 | 3.872 |
| 4.80 | 35.00 | 5.60 | 4.980 | 6.40 | 3.872 |
| 4.90 | 35.00 | 5.70 | 5.010 | 6.50 | 3.872 |
| 5.00 | 35.00 | 5.80 | 5.040 | 6.60 | 3.872 |
| 5.10 | 35.00 | 5.90 | 5.070 | 6.70 | 3.872 |
| 5.20 | 35.00 | 6.00 | 5.100 | 6.80 | 3.872 |
| 5.30 | 35.00 | 6.10 | 5.130 | 6.90 | 3.872 |
| 5.40 | 35.00 | 6.20 | 5.160 | 7.00 | 3.872 |
| 5.50 | 35.00 | 6.30 | 5.190 | 7.10 | 3.872 |
| 5.60 | 35.00 | 6.40 | 5.220 | 7.20 | 3.872 |
| 5.70 | 35.00 | 6.50 | 5.250 | 7.30 | 3.872 |
| 5.80 | 35.00 | 6.60 | 5.280 | 7.40 | 3.872 |
| 5.90 | 35.00 | 6.70 | 5.310 | 7.50 | 3.872 |
| 6.00 | 35.00 | 6.80 | 5.340 | 7.60 | 3.872 |
| 6.10 | 35.00 | 6.90 | 5.370 | 7.70 | 3.872 |
| 6.20 | 35.00 | 7.00 | 5.400 | 7.80 | 3.872 |
| 6.30 | 35.00 | 7.10 | 5.430 | 7.90 | 3.872 |
| 6.40 | 35.00 | 7.20 | 5.460 | 8.00 | 3.872 |
| 6.50 | 35.00 | 7.30 | 5.490 | 8.10 | 3.872 |
| 6.60 | 35.00 | 7.40 | 5.520 | 8.20 | 3.872 |
| 6.70 | 35.00 | 7.50 | 5.550 | 8.30 | 3.872 |
| 6.80 | 35.00 | 7.60 | 5.580 | 8.40 | 3.872 |
| 6.90 | 35.00 | 7.70 | 5.610 | 8.50 | 3.872 |
| 7.00 | 35.00 | 7.80 | 5.640 | 8.60 | 3.872 |
| 7.10 | 35.00 | 7.90 | 5.670 | 8.70 | 3.872 |
| 7.20 | 35.00 | 8.00 | 5.700 | 8.80 | 3.872 |
| 7.30 | 35.00 | 8.10 | 5.730 | 8.90 | 3.872 |
| 7.40 | 35.00 | 8.20 | 5.760 | 9.00 | 3.872 |
| 7.50 | 35.00 | 8.30 | 5.790 | 9.10 | 3.872 |
| 7.60 | 35.00 | 8.40 | 5.820 | 9.20 | 3.872 |
| 7.70 | 35.00 | 8.50 | 5.850 | 9.30 | 3.872 |
| 7.80 | 35.00 | 8.60 | 5.880 | 9.40 | 3.872 |
| 7.90 | 35.00 | 8.70 | 5.910 | 9.50 | 3.872 |
| 8.00 | 35.00 | 8.80 | 5.940 | 9.60 | 3.872 |
| 8.10 | 35.00 | 8.90 | 5.970 | 9.70 | 3.872 |
| 8.20 | 35.00 | 9.00 | 6.000 | 9.80 | 3.872 |
| 8.30 | 35.00 | 9.10 | 6.030 | 9.90 | 3.872 |
| 8.40 | 35.00 | 9.20 | 6.060 | 10.00 | 3.872 |
| 8.50 | 35.00 | 9.30 | 6.090 | | |
| 8.60 | 35.00 | 9.40 | 6.120 | | |
| 8.70 | 35.00 | 9.50 | 6.150 | | |
| 8.80 | 35.00 | 9.60 | 6.180 | | |
| 8.90 | 35.00 | 9.70 | 6.210 | | |
| 9.00 | 35.00 | 9.80 | 6.240 | | |
| 9.10 | 35.00 | 9.90 | 6.270 | | |
| 9.20 | 35.00 | 10.00 | 6.300 | | |
| 9.30 | 35.00 | | | | |
| 9.40 | 35.00 | | | | |
| 9.50 | 35.00 | | | | |
| 9.60 | 35.00 | | | | |
| 9.70 | 35.00 | | | | |
| 9.80 | 35.00 | | | | |
| 9.90 | 35.00 | | | | |
| 10.00 | 35.00 | | | | |

NOZZLE '3

FULL SCALE

ALL SURFACES TO BE FINISHED GROUND

MATERIAL - STEEL

PIECES #1 AND #2 ALIKE

PIECE 1

10.35°
STRAIGHT TUBE

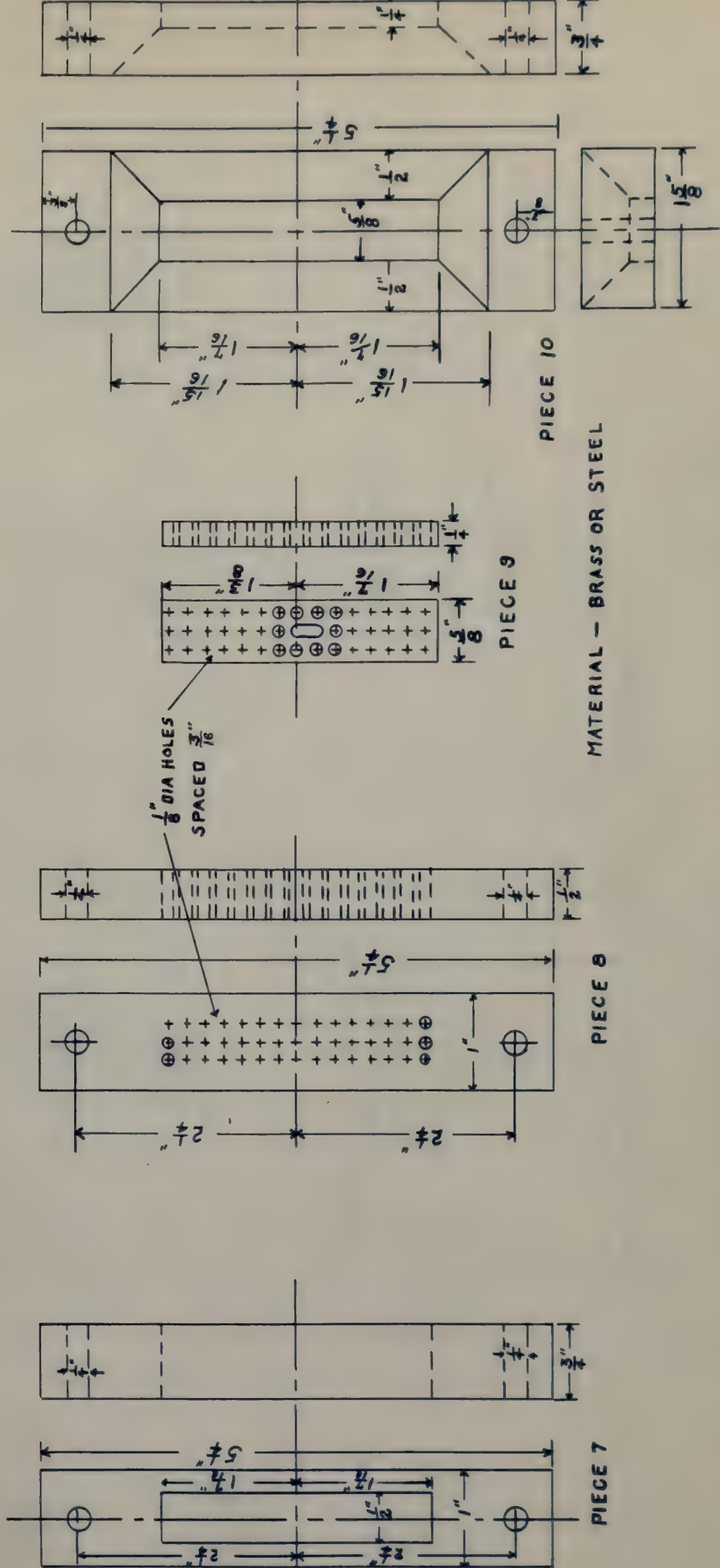
PIECE # 2

DRILL PIECE NO 2 ONLY

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FIGURE XXXIX

REDUCING FITTING



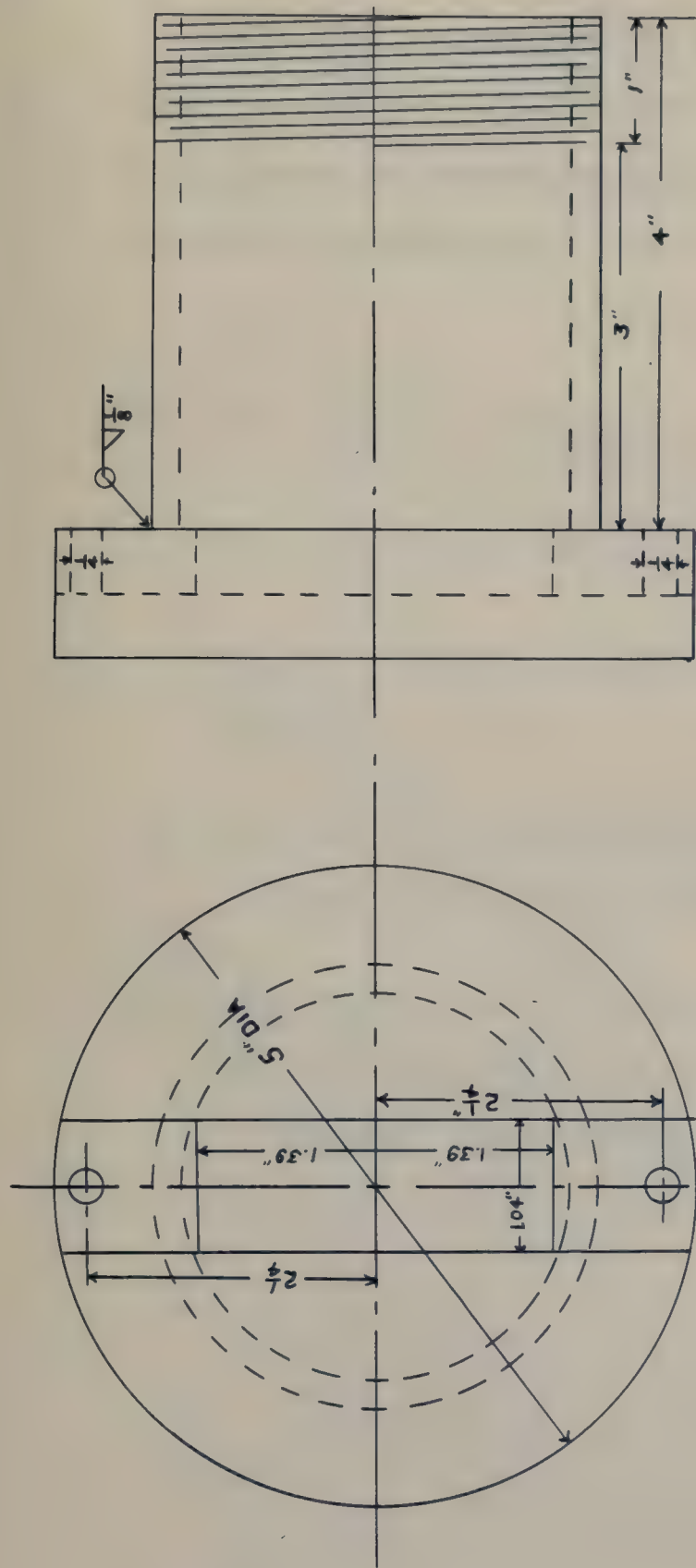
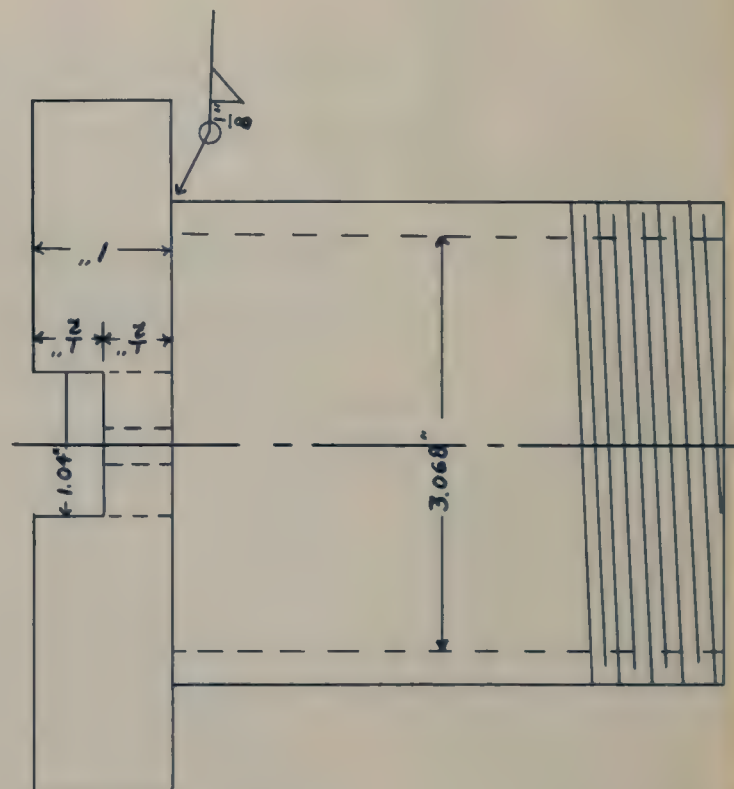
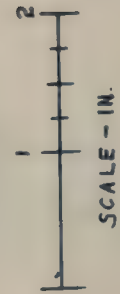


FIGURE XXX

EXHAUST FITTING

MATERIAL- STEEL



APPENDIX C -- LOCATION OF ORIGINAL DATA

All of the original nozzle design calculations, photographic negatives, and the nozzle profiles are in the possession of Mr. E. P. Neumann of the Mechanical Engineering Department, Massachusetts Institute of Technology.

All of the original source material, including photographs, negatives, and the source material for the production of the E. F. Johnson of the Mechanical Engineering Department, University of Technology.

APPENDIX D -- BIBLIOGRAPHY

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1947.

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Investigation of Supersonic Flow in Nozzles and Tubes, M.I.T., 1947.

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Thesis
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Perry

Schlieren observation of
supersonic discharge.

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Thesis

P34

Perry

Schlieren observation of super-
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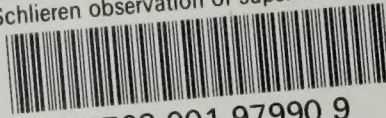
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